AN ABSTRACT FOR THE THESIS OF

Thomas E. Rollman for the degree of Master of Science in Electrical and Computer Engineering presented on May 23, 1996. Title: Operation of the Motor Systems Resource Facility.

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Abstract Approved: ________ ________
Alan K. Wallace

A state of the art motor testing facility has been built at Oregon State University. This is the largest independent testing laboratory of its type in the western United States. The construction was funded by a consortium of industrial sponsors, with a goal of becoming financially self-sufficient by charging the users for the services provided.

An operating philosophy has been developed which attempts to meet the diverse needs of all parties involved including the University, the industrial sponsors and the customers desiring either research or standardized testing services. To meet these needs a business plan was developed along with an efficient, yet flexible, process for safely testing equipment.

Safe operation of the laboratory is a prime consideration and has been addressed through system design and procedural safeguards. Unlike installations of similar equipment in industrial applications, this facility must accommodate a wide variety of motors and drives in temporary configurations without unduly hindering the testing process. Also, unlike many university based research projects this laboratory has the capability of delivering high power levels which can result in potentially dangerous situations if adequate safety precautions are not taken.

All of these objectives have been met and the laboratory is now in operation. As the volume of testing increases, further issues will be raised and addressed within the flexible operating structure which has been established.

Operation of the
Motor Systems Resource Facility

by

Thomas E. Rollman

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Thomas E. Rollman, Author

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1. INTRODUCTION

The Motor Systems Resource Facility (MSRF) is a new research and testing laboratory located on the campus of Oregon State University (OSU). This project was initiated in late 1993 by a consortium of sponsors to meet an identified, growing need for the industrial customers of electric utilities. This laboratory is designed to test a wide variety of electrical machines, adjustable speed drives and variable speed generators, and their related converters and controls in a safe and efficient manner. In addition to testing to recognized industrial standards, the facility is readily available as a source of advice, information, reference and instruction on issues and equipment related to electrical machines and their operation.

OSU was chosen as the site for the MSRF based on its history of successful projects in this area and the expertise and experience developed during ten years of providing similar services to regional utilities and industries. This previous testing was limited to 30 hp motors and smaller due to the electrical distribution system in the laboratory and the mounting fixtures available. The MSRF represents a significant increase in testing capacity, up to 300 hp, and a similar improvement in data acquisition and control systems bringing them up to state-of-the-art. The facility is operated by OSU College of Engineering research faculty, electrical and mechanical technical staff, and post graduate students. This facility represents an independent resource to industry combined with a research and education function for the University. The researchers are able to use modern, higher power systems, industrial customers are able to use a local, independent testing facility and students are able to work on equipment which is representative of systems they will encounter after graduation.

Successful operation of the MSRF requires several key features to be properly implemented. They are:

1. A technical design which allows thorough testing of a wide variety of motors and drives while collecting accurate data from which to evaluate their performance.
2. A business plan which allows the facility to become financially self-sufficient by charging users for the services provided.
3. An efficient testing process which yields reproducible results and remains flexible to meet the changing needs of the users.
4. An awareness of the safety issues which are then addressed through design and procedural safeguards.

This facility began operation in January 1996 and has attracted customer interest from each of the target areas described in the Business Plan.

2. OPERATION OF THE TEST CENTER

2.1 Technical Description

The Motor Systems Resource Facility utilizes a fully regenerative system capable of testing motors, generators and their controllers either as individual components or as complete systems. As shown in Figure 1, the incoming 480 volt, three phase electrical power is supplied by a dedicated utility connection rated at 750 kVA. The power is routed through Motor Control Center One (MCC-1) which is composed of circuit breakers for the protection of personnel and equipment. Then the power is directed to three 600 amp rated variable autotransformers which can be adjusted to provide from 0 to 600 volts output. This allows the voltage in each phase to be raised or lowered to provide industry standard 240, 480 or 575 VAC at either balanced or intentionally unbalanced conditions for the unit being tested. This power is then routed through Motor Control Center Two (MCC-2) for distribution to the appropriate loads. MCC-2 contains several circuit breakers of different sizes which can be adjusted to prevent damage to the equipment being tested. It also contains instrumentation which measures the rms current, rms voltage and power being supplied to the load. The power is then applied to the system under test (i.e. directly to the motor or through a controller to allow variable speed operation). The motor converts the electrical power to mechanical power which is then transmitted through, and measured by, a torque and speed transducer mounted on the test bed. A mechanical load is provided by the dynamometer machine which, with its solid state controller, converts the mechanical power back to usable 480 VAC, three

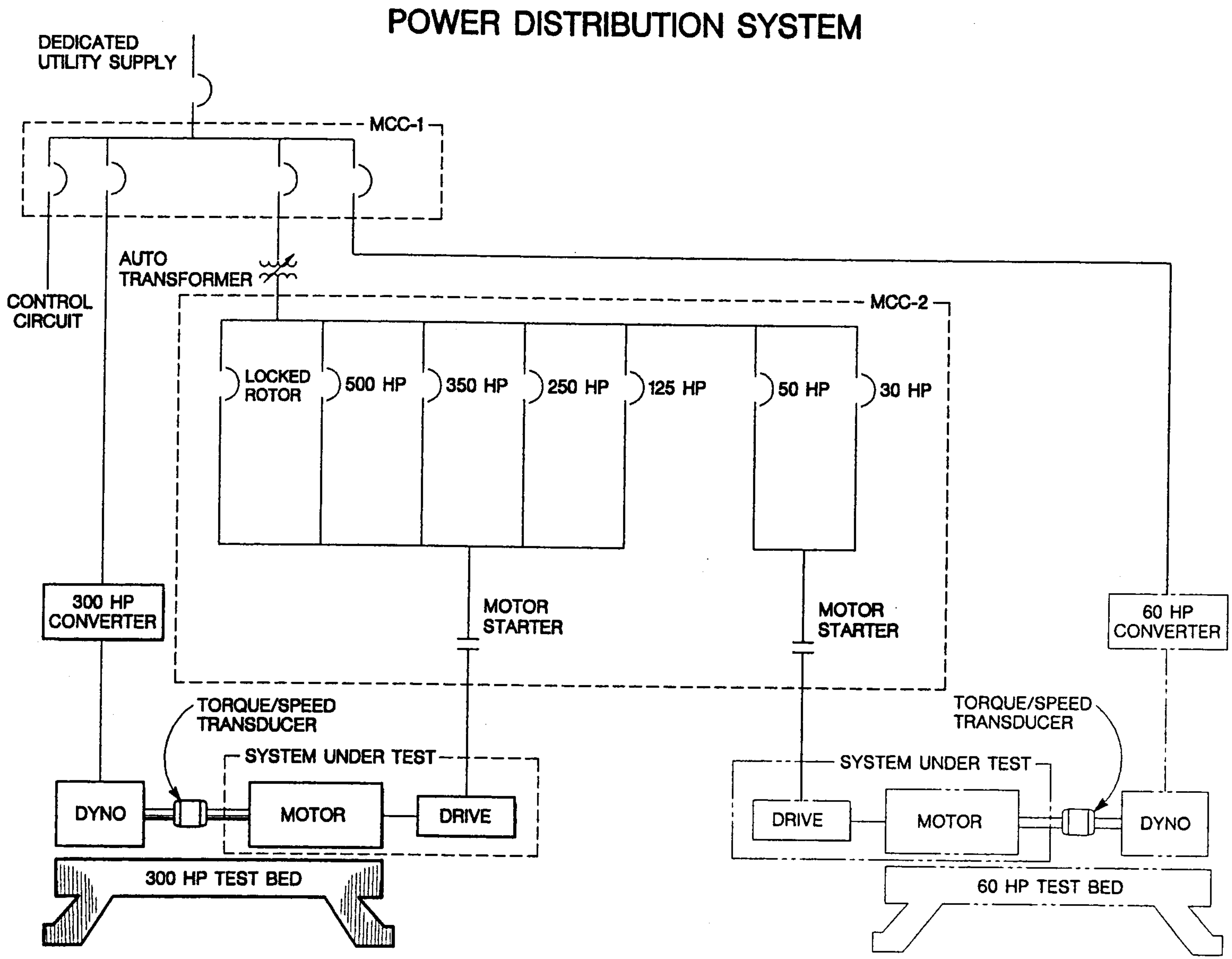
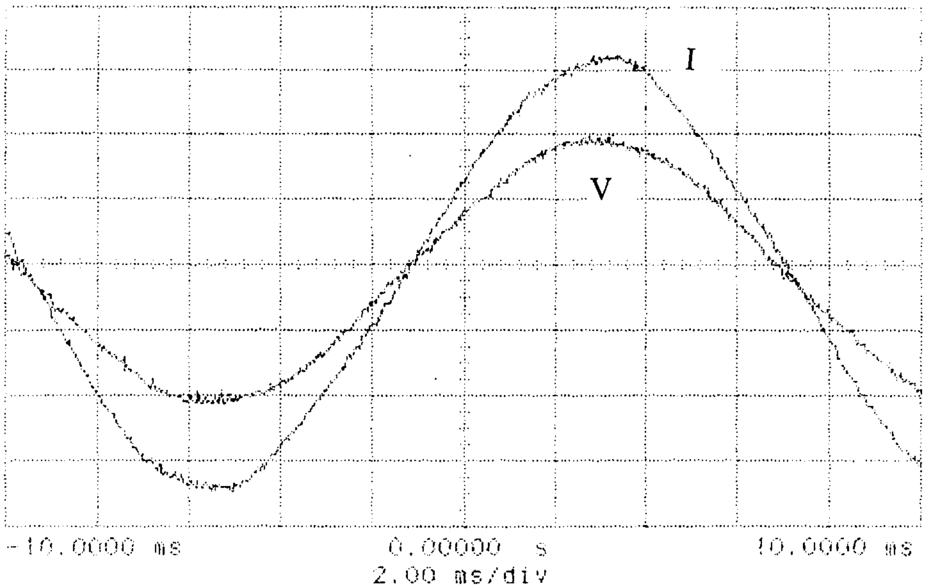


Figure 1 Power Distribution System

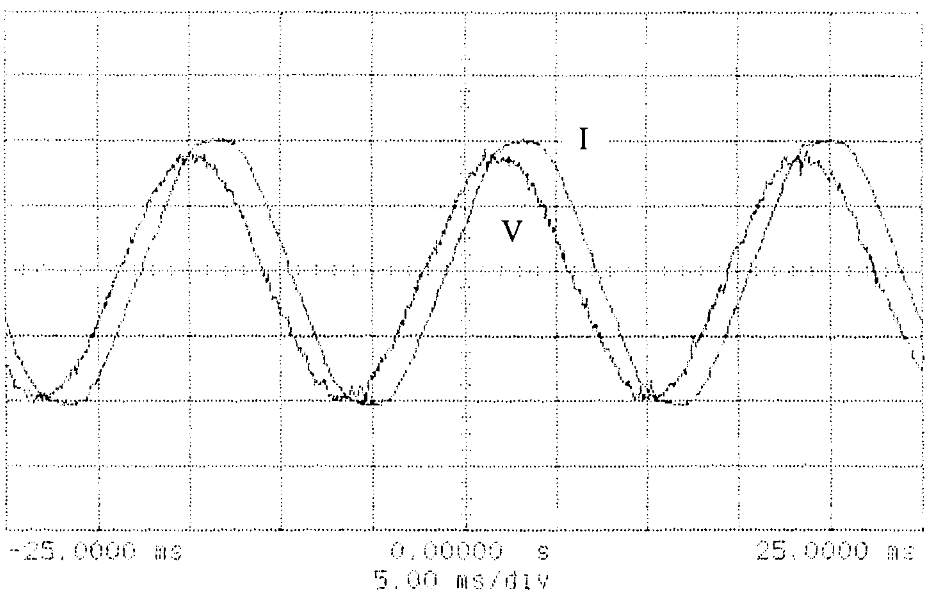
phase, 60 hertz electrical power, which is returned to MCC-1 for reuse by the system. Thus the only power which is provided by the utility is that which is dissipated in the form of heat due to mechanical and electrical losses. This value is typically 10 to 15% of the rating of the machine being tested versus the total power drawn by the load. Thus this regenerative design is cost effective on a capital investment basis by eliminating the need for additional equipment, such as complicated plumbing or air conditioning systems, and on an operating cost basis by greatly reducing electricity consumption.

A complete description of the test system and the instrumentation is contained in a thesis by Timothy M. Lewis [1]. One significant operational aspect which had not been demonstrated prior to work for this current thesis concerns the effects of using the recirculated power to drive the system under test. At the time of the operations documented in [1] only temporary electrical connections were available and only limited testing had been completed. Since that time a variety of tests have been completed using the permanently installed instrumentation and the dedicated utility supply. This testing has revealed that a) the regenerated power contains less than 2% Total Harmonic Distortion (THD) at full load as shown in the oscilloscope traces of Figure 2 and b) the dynamometer does not cause unstable power oscillations with the unit under test.

Further testing has revealed that a small amount of electrical noise is generated which originates in the converter and test motor, which is most noticeable at low power levels. Figure 3 shows the distorted current and voltage waveforms and spectral graph at the test motor terminals under 10% (20 kW) load. The dynamometer converter synthesizes the desired waveforms using pulse width modulation at a switching frequency of 5.96 kHz on the line side and 5.60 kHz on the dynamometer side. Additionally, the

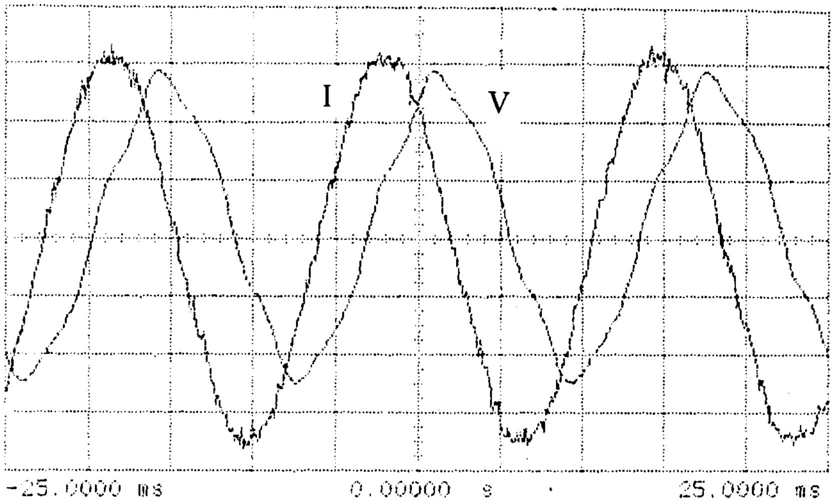


Full Load Voltage and Current at Converter Terminals

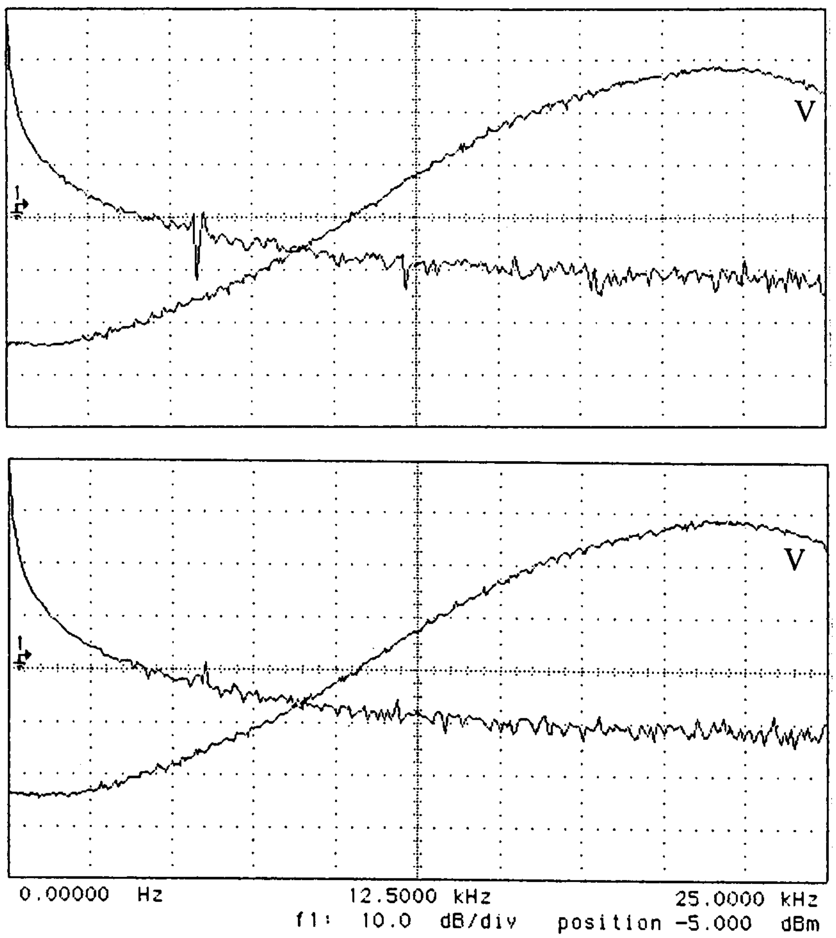


Full Load Voltage and Current at Test Motor Terminals

Figure 2 Full Load Power Distortion



10% Load Voltage and Current at Test Motor Terminals



10% Load Spectral Graphs at Test Motor Terminals

Figure 3 Low Load Power Distortion

converter uses a 5.7 kHz sampling rate set by a crystal oscillator. Most of this noise is filtered using line inductors to reduce the amount of distortion on the incoming line. This noise occurs at approximately 6 kHz and its harmonic values at 12, 18 and 24 kHz. Since the switching and sampling rates are not synchronized between themselves or between the three phases, they tend to add or cancel at seemingly random intervals. Therefore, the spectral graph varies depending upon the instant the data is collected as shown in the two graphs of Figure 3 taken only seconds apart. In addition, the motor being tested also generates noise on the incoming line due to slot harmonics. Since the rotor and stator are not ideal devices their windings are not arranged in a truly sinusoidal distribution. This causes the motor to draw current which is not sinusoidal as the rotor turns within and interacts with the stator magnetic field. These distortions occur several times during each electrical cycle and repeat at regular intervals, as seen in the voltage waveform at the motor terminals shown in Figure 2. Neither of these sources of noise exceeded the 5% THD voltage distortion limitation of IEEE 519, even at power levels of 20 hp. Therefore, by themselves they do not establish a lower limit on the capabilities of the test bed.

2.2 Business Plan

The MSRF currently operates as a laboratory within the Electrical and Computer Engineering (ECE) Department of Oregon State University. An ECE faculty member serves as the Director of the MSRF with the staff consisting of a secretary, student workers, technicians and other faculty members, each working on a part-time basis as needed, to support the operation of the facility. The goal of the MSRF is to become financially self-sufficient such that income generated by the services performed for customers is able to cover all of the expenses of operating the laboratory. This includes: salaries; travel for meetings, promotional activities and conference participation; marketing material; office supplies; laboratory equipment and maintenance; and general facility upgrades to expand the laboratory's capabilities. The marketing efforts to attract new customers include presenting papers at technical conferences, distributing brochures and video tapes describing the MSRF's capabilities and establishing a world wide web page available to all parties on the Internet. The MSRF Business Plan is included in Appendix A.

2.3 Process Description

In order to comply with University requirements and still meet the needs of the customers for fast, accurate and cost effective testing services, an efficient testing process had to be developed. Also, to ensure uniform results from one test to the next, procedures had to be implemented. This is particularly important when the primary operating staff, student workers, has a complete turnover every two to three years. This means that new personnel are constantly being trained and the "corporate history" is limited to the faculty and staff members serving in a part-time capacity.

The service and testing process (as shown in Figure 4) begins when a potential customer initiates contact with a staff member. Regardless of how the individual became aware of the facility, they will be inquiring by telephone, fax, letter or email about how the facility can meet a need that they have. The staff member will attempt to collect as

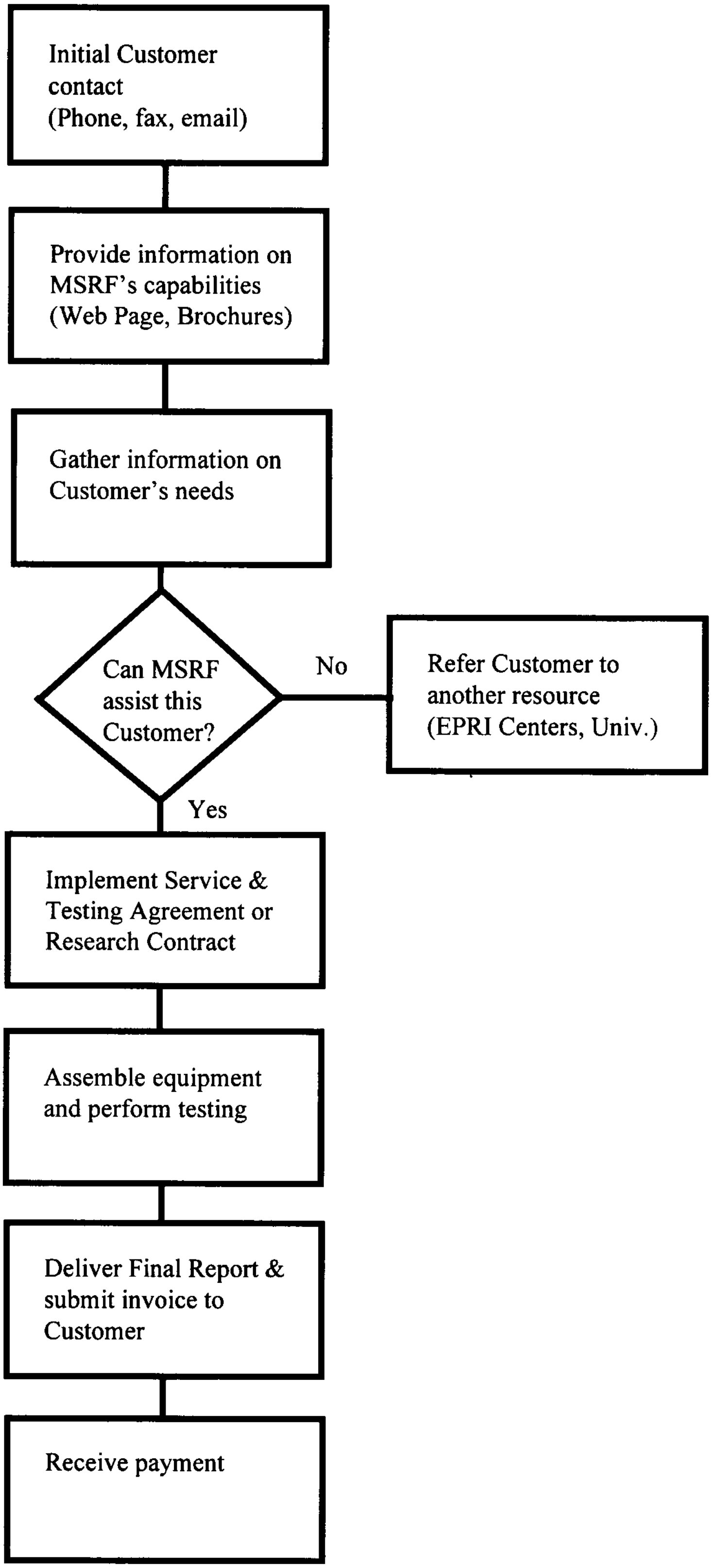


Figure 4 Flowchart of Testing Process

much information as possible about this need to determine if the MSRF can be of assistance. If it is clear that the center does not have the facilities or expertise required, the person will be referred to other facilities better suited to help them. If the customer desires further information, they will be referred to the world wide web page for general information which is immediately available to them. If the person does not have access to the Internet or desires additional information, brochures (and perhaps videotapes, public domain reports of previous tests or conference papers) will be mailed to them. Specific questions will be answered by telephone, fax or email as appropriate. Above all the customer must feel that their inquiries are being handled in a professional and timely manner, otherwise they will feel that this is how their project will be treated.

The information sent to the customer may include the MSRF tri-fold brochure for general information, the new color brochure and any single page inserts which are appropriate for the type of testing to be performed. If standardized testing is anticipated, a price list and a copy of the Service and Testing Agreement will be included along with a cover letter inviting further communication.

If the customer then chooses to use the MSRF, they may send a letter requesting the desired services, submit the Service and Testing Agreement along with the Work Order or ask the MSRF to initiate the Agreement. In any case, a Service and Testing Agreement will be prepared which includes a Work Order describing the services to be performed and the price of those activities. This amount may be a fixed price, as for standardized testing, or an hourly rate for use of the facilities and personnel with a not to exceed value established. The Work Order is unique to each job and specifies what work is to be done, the responsibilities of each party, handling of proprietary data, the schedule of activities including items to be coordinated with other parties, and any critical milestones or decision points. After both parties agree to the scope of work and price, the Agreement is signed by the customer, the Director of the MSRF and the University Contract Administrator. In routine cases approval by the University is expected to take no more than one day, thereby ensuring timely response to the customers' needs.

If the testing requires assets not available in the MSRF, the Director must determine how to acquire these items. For example, hardware may be loaned from other University departments, rented from commercially available sources, fabricated, purchased or supplied by the customer. The decision will be based primarily on the availability of the item and its anticipated demand in future testing. This process may be applied when acquiring specialized tools, drives, power supplies, instrumentation, mounting fixtures or software.

After the Service and Testing Agreement has been approved, the Director assigns one or more student workers as Test Director(s) to organize and conduct the tests. The Test Director then gathers the equipment, prepares the test procedures and schedules the time needed for the testing. The equipment is operated by the student workers assigned to the laboratory to ensure that personnel and equipment safety procedures are followed. The Test Director ensures that the technical objectives and data collection requirements are met. After the testing is completed, the Test Director analyzes the data, prepares the data for archival storage and prepares the final report to be delivered to the customer. A copy of the final report is maintained in the MSRF's data library along with a copy of the raw data collected and any supporting information. The Director oversees this entire process ensuring that the technical and contractual requirements are met in a safe and efficient manner.

Upon completion of the testing, or as agreed upon in the Work Order, an invoice is delivered to the customer. In addition, customer feedback is sought via telephone, fax or letter to see if their needs have been met and to solicit recommendations for improvement. Obtaining this feedback is absolutely essential if the facility is to continue to develop and meet the needs of its customers for years to come.

If the customer desires to conduct research testing in the laboratory, the process described above is modified slightly. The primary characteristic which determines whether the testing is classified as research is if there is an intent to develop intellectual property, which then belongs to the MSRF, or the customer, or is shared between the parties. Instead of using the Service and Testing Agreement described above, a Research Proposal containing a Statement of Work is submitted to the customer by the MSRF and is approved by the customer, the Director of the MSRF and the University Dean of Research. Generally, these Research Agreements are unique to the testing to be performed and therefore take longer to negotiate than standardized testing agreements. They may contain special provisions for data collection, how the testing is conducted, handling of proprietary data, etc. This testing may span several weeks or months with several decision points based upon the results achieved in preceding steps. In nearly all cases, the research testing will be priced based on the hourly rates of the test center and the personnel involved.

3. SAFETY CONCERNS

For this facility to remain in operation the order of priorities are and must be 1) safety of personnel, 2) safety of both the laboratory's and customer's equipment, and 3) performance of the testing activities. Therefore, to operate the laboratory the safety issues must first be identified and understood, and then addressed through either design or procedural safeguards, while retaining adequate flexibility to operate the facility.

3.1 High Voltage and Current Capability

This facility represents a significant increase in capacity from any of the University's previous testing facilities. The incoming power available to this laboratory rivals that used by the remainder of the building for lighting, computers, ventilation and all other laboratories combined. The previous laboratories were limited to 240 VAC and 50 amps. This new laboratory can supply up to 600 VAC and over 1200 amps, equivalent to a 50 fold increase in power. This presents new problems which were not routinely encountered in the past. For example, instrumentation probes and connector insulation methods which were satisfactory at lower voltages are no longer acceptable. Probes with partial degradation of their electrical insulation may work fine at lower voltages, while causing arcing and resultant damage at 480 volts. Also, the practice of moving probes between test points on an energized circuit does not pose too great a risk at 120 volts or even 240 volts, but at 480 volts and above the practice can easily result in personnel injury and equipment damage. Similarly, the use of only electrical tape to insulate exposed connections should also be avoided since this tape is easily punctured and damage to it is difficult to detect until it results in arcing or a shock to personnel.

Operating equipment at higher power levels results in a need for greater heat dissipation. Even with proper cooling maintained, often localized hot spots develop. This condition is aggravated by enclosing equipment for personnel safety, which causes confined spaces that frequently do not receive sufficient air flow for cooling. In addition, if adequate wire sizes and connectors are not available, personnel may be tempted to use smaller diameter wire than that specified in the National Electric Code. This causes even greater heating of the wire. All of these elevated temperature situations and repeated flexing of the cable during equipment installation and removal results in accelerated degradation of the electrical insulation. Once the dielectric strength is lost and the insulation becomes brittle, electrical faults, short circuits and exposed conductors can develop. Since these circuits are able to deliver much more current than in other laboratories, the failures often result in much more damage. For example, a low resistance path of 100 ohms through a piece of equipment or a human body results in 1.2 amps in a 120 volt circuit. Often the over current condition is sensed by a protective device such as a fuse or circuit breaker and the source is isolated to prevent further damage. In any event, this condition represents only 144 watts which must be dissipated. Using the same path in a 480 volt circuit results in a current of 4.8 amps and a power of 2304 watts, sixteen times the previous power level. In this situation, it is unlikely that the protective devices will be activated because the current through the fault is small when compared with the normal load. Also, the increased power that must be dissipated can cause further breakdown of the electrical insulation and ionization resulting in even more current flow and more power to dissipate. Therefore, a fault which causes simple arcing at 120 volts can, at 480 volts, result in fires and molten metal from arcing as well as debris projected from explosions.

3.2 Temporary Connections

In a typical industrial application the power distribution and monitoring equipment is installed, connected to the loads and tested. Permanent connections are used, cables are run through protective conduit and circuit breaker set points are established to protect the equipment during steady-state and transient conditions. The loads are relatively fixed and few adjustments are made once the system is operating properly. In contrast, to enhance the flexibility of the MSRF several connection points are available from which to draw the electrical power, along with multiple breakers being able to feed the same load. The laboratory is also designed for testing and research to allow loads to be connected quickly and easily and to enable data acquisition at several locations simultaneously. This requires connectors which are frequently attached and removed as well as cables which are not run through conduit for at least part of their length. In some cases, connectors must remain exposed to allow instrumentation access for data collection and trouble shooting. Such connections are highly susceptible to electrical shorting from instrumentation probes, dropped tools and loose parts. Although undesirable from purely a safety viewpoint, these configurations are often necessary to allow testing to proceed in a reasonable time period and at a reasonable cost.

3.3 Rotating Machinery

The high capacity circuits in the MSRF are used to drive larger motors and loads than could previously be tested. This results in higher mechanical forces which must be respected and handled appropriately. Any imbalance results in vibration which can loosen connections, both electrical and mechanical, causing arcing, misalignment and unrestrained fasteners which then become projectiles. For example, a single bolt attached to one of the flexible couplings weighs 1.5 ounces. Since,

Velocity = angular frequency x radius,

when traveling at 3600 rpm at a radius of 4.75 inches, if the bolt breaks free it will have a velocity of 45.5 meters per second or 102 miles per hour. At this weight and speed the bolt has the potential to cause serious injury if it strikes a person.

Also, if the shaft of the machine is restrained due to misalignment, locking devices or debris in the area, pieces of the couplings and mounting hardware can become projectiles with a great deal of speed and energy. Loose clothing and cables can also become entangled with the shaft and cause considerable damage. In all of these cases, the same concerns existed in the smaller facility but the consequences can be much more severe when dealing with larger motors.

Building a larger and more sophisticated testing laboratory required more automation to collect data and operate equipment. In the new facility devices are controlled remotely from the control room and a higher background noise level makes traditional audible detection of problems more difficult. Also, power converters are used to supply the motor under test as well as to control the load of the dynamometer. Since one machine represents a load to the other machine the forces must be balanced precisely to prevent instability. When supplying a nonregenerative load, such as a water brake, loss of power to the drive motor results in a shutdown of the system. In a regenerative system, loss of the drive motor can result in reversal of the direction of rotation, overspeed of one or both machines and other high stress transients. The dynamometer converter operates in either the torque or speed mode. In the torque mode, the dynamometer maintains a constant shaft torque to load the motor being tested. When power is lost to the test motor, it can no longer provide torque to the shaft and the dynamometer quickly reverses direction and accelerates due to its constant torque setting until it reaches its maximum speed. Likewise, in the speed mode the dynamometer will attempt to hold the commanded speed regardless of what happens to the motor being tested. Therefore, if the load on the shaft suddenly increases due to mechanical binding or bearing failure the dynamometer will apply as much torque as needed, within its allowable limits, to maintain constant speed. This can result in mechanical failures, fires and other hazards.

3.4 Energy Storage Devices

To function properly and to reduce the harmonic frequencies generated on the electrical grid all solid state motor controllers require filtering devices to temporarily store electrical power. This energy is controlled by solid state devices operating very close to their rated values and is stored in inductors and capacitors throughout the motor testing facility. During normal operation these storage devices are in an equilibrium condition, when averaged over several electrical cycles. However, during transient conditions they may be called upon to either supply or sink large amounts of instantaneous power. This can result in damage to the energy storage devices and other components in the circuit. When these devices fail they must rapidly release their stored energy and often provide a momentary short circuit or ground path for the energized circuit. This can result in arcing and a possible explosion caused by rapid heating of the air. In addition, when electrical power is removed from the motor controller these devices retain their energy for some period of time. Inadvertent contact with these components before the voltage has had time to decay may result in personnel injury. For example, in the dynamometer converter the DC bus is maintained at 900 volts using a large bank of capacitors. This charge requires a minimum of five minutes to decay to a safe level. The total energy stored in this capacitor bank is 10,700 joules.

Stored Energy = half the capacitance x square of the voltage

If this power was released in 1 millisecond during a fault or accident the power level would reach 10 MW during that brief period.

In addition to the electrical energy, mechanical energy is stored in the form of shaft inertia. The rotors of the dynamometer and machine under test combined with the torque/speed transducer and mechanical couplings weigh several hundred pounds. The low friction bearings required for high efficiency during normal operation allow the shaft to rotate for over 10 minutes once electrical power is removed from the motors. If a problem develops and the shaft must be stopped quickly, this rotational energy must be dissipated. When a large motor is connected to the dynamometer, the combined rotor shaft weighs over 1000 pounds.

Moment of Inertia = mass x square of radius / 4

Kinetic Energy = half the Moment of Inertia x square of the angular frequency

When this assembly is rotating at 3600 rpm it possesses 61,300 joules of kinetic energy, the equivalent of a 4,000 pound car traveling at 18 miles per hour. Clearly, this configuration can exert enough force to harm any individual even if the electrical power is removed immediately.

4. DESIGN SAFEGUARDS

4.1 Selection of Breakers and Settings

The power distribution network for the laboratory is shown in Figure 1. All of the power from the dedicated source passes through a common circuit breaker outside of the building housing the laboratory. The breaker frame is rated for 3000 amps and has a rating multiplier plug which allows the breaker to trip at an overcurrent value of 1200 amps. Ground fault protection and trip indication are also provided with this breaker. The power is then delivered to MCC-1 where it feeds four additional breakers. These breakers range in size from 15 amps to 800 amps with the major breakers offering ground fault protection. One of these breakers feeds the autotransformers and then MCC-2. MCC-2 contains seven breakers ranging in size from 90 amps to 1000 amps to accommodate the different power and voltage requirements of the motors to be tested. These breakers feed the two test platforms containing the motors and drives being tested. Several of these breakers also have ground fault trips. This cascaded arrangement is similar to that found in all industrial applications. It allows the smallest (most sensitive) breaker to feed a particular load or circuit thus protecting the motor, drive and wiring from further damage. Any overcurrent condition trips this breaker without waiting for a higher setpoint to be reached on an upstream breaker and consequently other unaffected loads are not disturbed due to the failure of one component. For this application, the smallest breaker which meets the full load requirements is used to supply the machine under test. In several of the MCC-2 breakers the trip setpoint can be adjusted to provide the exact setting for the particular load being tested.

The ground fault trip uses a residual sensing scheme to determine the amount of current flowing in the grounded conductor. If this current level exceeds the value established by the sensor on the breaker for a selected time period, the breaker will trip. This protects the equipment in the event of an inadvertent ground path through the equipment or in the cabling.

Because of the nature of testing being performed and the likelihood of spurious or unknown causes of trips, an additional device was purchased and installed in one of the circuit breakers. This module displays true rms current flowing through each phase of the circuit breaker, peak ground-fault current and the cause of a trip, whether it is overload, short circuit, or ground fault.

4.2 Emergency Shutdown Switches

After a mishap during the construction of the facility it became obvious that during certain accident situations the operators may not be able to safely shutdown systems being tested or they may become confused and not take the proper actions due to the stress of the moment. In such a situation when, literally, sparks are flying and people are running for cover it is very reassuring to have a “panic button” which, when pushed, removes all of the high power capabilities from the laboratory. In the original design the operator could only send a command to shutdown the dynamometer converter and open the motor starter from the control room. Opening the circuit breakers required entering the laboratory to reach MCC-1 and MCC-2, or walking outside the building to reach the circuit breaker for the dedicated power source. Neither option was particularly attractive during an actual emergency.

To avoid this problem and to give the operators greater control two emergency shutdown switches were added which provide a shunt trip signal to the main circuit breaker supplying the dedicated power to the laboratory. As shown in Figure 4, 120 volt power is obtained from the normal building power source through an isolation transformer. When this 120 volt signal is applied to the shunt trip device, the breaker opens and power is removed from both the system under test and the dynamometer, effectively removing all but 120 volt power from the laboratory. In an accident situation, the operators only need to hit one of the switches located near the exits to the control room and the laboratory, without having to decide from where the power is supplied. This will isolate any high power equipment which must be shutdown immediately, without affecting instrumentation power or lighting.

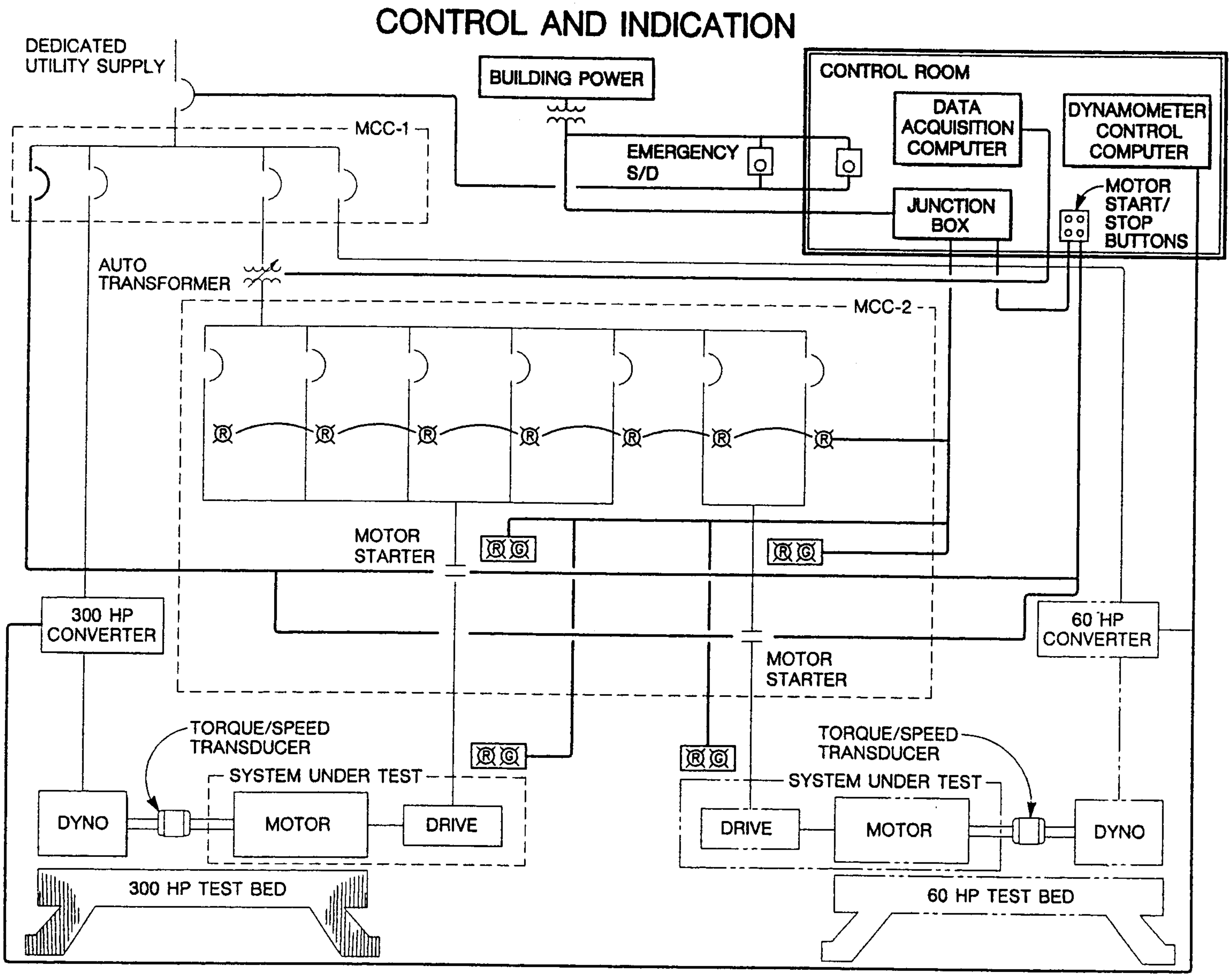


Figure 5 Control and Indication Power

4.3 Control System Power

Simplified diagrams of the Control and Indication Power and the Instrumentation Power are shown in Figures 4 and 5 respectively. These figures indicate the sources of power and locations of control and indication devices in the laboratory. A detailed description of the Control and Instrumentation features is contained in [1] and [2].

4.3.1 Dynamometer Converter Control

The dynamometer converter receives commands from a dedicated computer in the control room. This computer is completely separate from the one used for data acquisition. By having two operator stations, it allows more complicated testing procedures than a single operator could reasonably monitor and minimizes the possibility of inadvertent keyboard or mouse actuation. Also, by having the control program on the screen at all times it allows more rapid detection and correction of problems which may arise during testing. In this case the operator is able to continually observe the monitored parameters and shut down the converter with a single keystroke.

The converter contains an EPROM with predetermined setpoints which the operator may not override. These values were determined by the manufacturer for safe operation of this converter with this induction machine. The control computer allows the operator to set more restrictive limits to protect the system being tested. For example, the operator may set a maximum speed of 1000 rpm when testing an eight pole induction machine, which normally runs at 900 rpm, while the EPROM value is 4000 rpm. Similar setpoints are provided for the maximum current, acceleration, deceleration and torque.

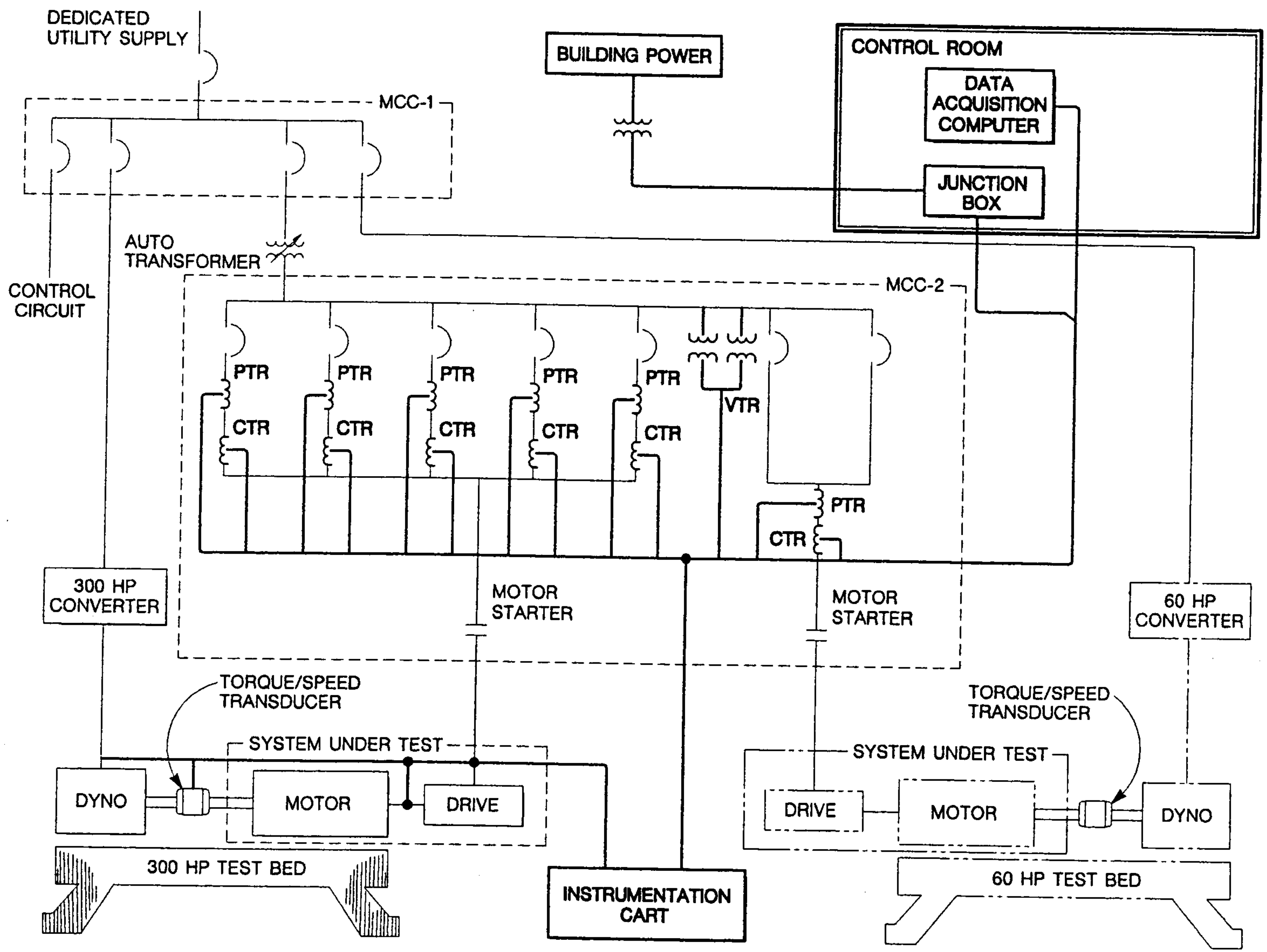


Figure 6 Instrumentation Power

4.3.2 Motor Starter Control

Closing the motor starter relay is the final step in supplying power to the system being tested. After the appropriate circuit breakers are closed, the relay contacts are closed using either the push button on the starter cabinet or in the control room. Again, these are dedicated switches to prevent inadvertent operation from one of the computer stations and to allow the operator easy access in the event that a rapid shutdown is needed. The original design called for these contacts to be computer controlled from the control room, however, after further consideration the decision was made to install dedicated switches. These contacts may returned to computer control at a later date if it can be shown that the operator can provide greater control during testing without compromising safety.

The electrical power for the motor starter relays is provided by building power via an isolation transformer as shown in Figure 4 and not the dedicated power source. The loss of either the 480 volt supply or the 120 volt control power results in the motor starter relay contacts opening and deenergizing the system being tested. As a further enhancement, the control wiring was changed to prevent the system being tested from inadvertently starting when power is restored. Now the operator must push one of the buttons to close the motor starter relay contacts following a loss of electrical power.

4.4 Common Ground Connection

In many laboratory and industrial settings it is difficult to take accurate measurements due to a difference is ground potentials between the points being measured and that of the instrumentation. To eliminate this problem, many experienced technicians remove the ground connection from their instruments. This "floating" ground can result in significant potential differences between the instrument case and other equipment in the area. In many cases this practice has lead to personnel injury and equipment damage. To eliminate this problem and to allow collection of accurate measurements the laboratory uses a single, well established ground connection. This grounding grid is located beneath the main circuit breaker supplying the dedicated power to the laboratory and is run along with the cables for the dedicated power source. Through another design modification, the 120 volt control power originating from the building power source is now provided via isolation transformers to remove the reference to the building service ground and then run with the separate laboratory ground. This power feeds the loads in the control room, the permanently installed instrumentation in the laboratory and the electrical outlets which supply the portable instrumentation. This places all the instrumentation in the MSRF at the same ground potential as the equipment being tested thus ensuring safety in the event of failures and an absence of potentially troublesome ground loops.

4.5 Indicator Lights

Another design modification involved the addition of indicator lights on the front of each circuit breaker in MCC-2 and each test bed, as shown in Figure 4, to assist the operators in determining whether the breakers and switches are in their proper positions. The circuit breakers have a single red light indicating that the breaker is in the closed position. A quick glance by the operator will reveal if one or more breakers are closed. In addition, each motor starter cabinet is equipped with a green light indicating that the relay contacts are open and a red light indicating that the contacts are closed. Redundant red and green lights are provided on the corresponding test beds. All of these lights contain a "push to test" feature to quickly determine whether the bulb is functional.

4.6 Explosion Proof Glass

To protect occupants of the control room during testing, explosion proof glass has been installed over the window and door connecting to the laboratory. These laminated pieces consist of three layers of one-quarter inch thick tempered glass bonded together. They are designed to absorb the energy from debris which may be discharged from any of the sources produced during testing, as discussed in Sections 3.3 and 3.4. When combined with the remote controls in the control room, this allows the operators and observers complete safety when conducting initial tests of new systems, tests designed to extend previously demonstrated safety levels and other tests which may produce unexpected results.

4.7 Shaft Coupling Guards

To protect operators and observers in the laboratory, shaft coupling guards have been installed over the torque/speed transducer and shaft couplings connected to each machine. These guards are designed to deflect material which may be expelled from or as a result of the rotating shaft during testing. In addition, they also reduce the possibility of injury or damage due to entanglement of clothing, hair or cables. When dealing with smaller motors this is not as severe an issue because in many cases the motor will simply stall and not produce any damage. However, when dealing with motors in the 300 hp range the motor will not stop until the operator takes action to remove power from the system, which would be well after any injury or damage has already occurred. A mechanical brake could be added to dissipate the rotational energy calculated in Section 3.4 thereby stopping the shaft in the event of an emergency, but it is highly unlikely that the operator would be able to recognize the problem and respond in time. Since the system cannot respond quickly enough to prevent injury or damage, the opportunity for entanglement must be minimized as much as possible.

5. PROCEDURAL SAFEGUARDS

5.1 Requirement to Use Procedures

As previously discussed in Chapter 3, the consequences of operator error or equipment failure at these power levels can be devastating. In a standard industrial application, the equipment would be fed from a single source and protective equipment would be sized to include all steady state and normal dynamic conditions. Consequently, in such an industrial environment design safeguards are able to protect the equipment and personnel in nearly all situations. However, due to the nature of the testing activities to be performed in the MSRF and the desired versatility goals this approach is not practical. For example, more than one circuit breaker can deliver electrical power to each test bed, temporary equipment must be installed and removed frequently, and tests frequently yield unexpected results due to their research aspect. Because of this wide variety of testing requirements and the constant turnover of student workers, the operators cannot be expected to memorize all of the information needed for safe operation of the laboratory. Instead, procedural safeguards must be used to ensure that equipment is operated within its design limits, that unnecessary risks are not taken and that safety is not compromised because of a lapse in memory or attention to the matters at hand. Examples of the startup and shutdown procedures are included as Appendix B. These procedures clearly state precautions that must be taken, the initial configuration the equipment should be in before proceeding and step by step instructions to serve as a checklist.

5.2 Trained Operators

To ensure that the procedures are followed correctly a training and qualification program must be established. This program must make the operators aware of the existence of the procedures, how they are to be used and how to resolve questions or discrepancies which may arise. The Director grants his approval after an operator has been properly trained and the Director feels that this individual can operate the equipment in a safe manner. To achieve this qualification the individual must demonstrate proficiency in each of the areas specified below.

- Trained to administer CPR and who to notify in case of an emergency.
- Operation of the converter control system.
- Operation of the data acquisition system.
- Safe startup and shutdown of all systems involved. (This includes the sequence of operation of all switches and breakers, adjustment of circuit breaker setpoints and adjustment of the autotransformers.)
- Simultaneous operation of multiple systems in the laboratory.
- Knowledge of conductor and connector ratings, both voltage and current.
- Knowledge of how the power is routed to each piece of equipment so that it can be quickly isolated in case of an emergency.

To ensure that unnecessary risks are not taken by the operators, the Director's permission must be obtained or he must be notified before proceeding when any of the following events occur.

- A circuit breaker trips twice when it is being closed.
- Any equipment is being used in a non-standard configuration.
- Any personnel injury.
- Any equipment damage.

The Director may then decide to investigate the matter further, modify the testing procedure, assign additional safety precautions or terminate the test.

5.3 Access to Laboratory

To guard against accidental injury to curious visitors all doors leading to the laboratory are shut and locked while testing is in progress. This prevents unauthorized personnel from entering the laboratory unnoticed while equipment is energized. In addition, the locks on the doors are different than for the other laboratories in the building to limit the distribution of keys which will allow entry to the area.

While any testing is in progress, there must be one operator present who meets the requirements outlined in Section 5.2 above. As a further safety requirement two people must be present whenever any of the following activities are taking place.

- Connecting or disconnecting power leads.
- Working on or near rotating equipment.
- Opening or working in any cabinet of MCC-1 or MCC-2.
- Closing any major circuit breakers on MCC-1 or MCC-2.

This is to ensure that if one person becomes injured, another is immediately available to render assistance and call for help.

6. CONCLUSIONS

The MSRF has proven to meet its design goals by providing a modern, flexible research and testing facility capable of meeting the needs of its users for years to come. A Business Plan has been prepared and implemented which allows the facility to operate in an efficient manner to meet the time and cost constraints of its standardized testing customers as well as the ever changing needs of its research users. The administration process has been streamlined to eliminate unnecessary delays while retaining required oversight to ensure compliance with governmental and University policies.

Similarly the testing process has been structured to reduce unnecessary complication and confusion. Systems have been designed to allow testing of a wide variety of equipment in a safe and professional manner. A training program and procedures have been initiated to ensure that operators have the necessary skills, knowledge and supervision to avoid personnel injury and equipment damage.

These documents provide the basis needed to ensure that the MSRF operates in a safe and efficient manner and is able to meet the needs of its current users. The flexibility which has been included in the design to allow new and expanded capabilities to be added as well as the adaptable organizational structure which has been implemented should allow the facility to continue to serve its users for many years to come.

An investigation into the effects of using electrical power which is recirculated within the system revealed that the distortions of the voltage waveforms are well within the allowable limits. The dedicated power source has a sufficiently low impedance to minimize the effect of electrical noise from one component being transmitted through to other components. Also the line filter installed on the dynamometer converter removes most of the harmonics which are generated during the pulse width modulation process to deliver a reasonable sine wave even at low power levels. Testing at low loads (less than 10%) revealed that the voltage waveforms contained less than 1% THD, making it quite acceptable at the motor terminals. Therefore, the lower limit for testing motors on the 300 hp test bed is more driven by the compatibility of the mounting fixtures and precision of the installed instrumentation rather than by the quality of the recirculated power.

Construction delays, primarily caused by late equipment deliveries, resulted in startup funds being reassigned to cover added installation costs. As a result, funds were not available to purchase many of the items needed to operate the facility. Delays in receiving additional funding from the sponsors has temporarily resulted in a virtual shutdown of the MSRF. Because of the uncertainty of sponsor funding and to prevent similar problems from occurring in the future, the following recommendations are made.

- Assign one person to work exclusively on marketing activities for a minimum of six months. This will make potential customers aware of the MSRF and its capabilities. Beyond that, "word of mouth" will continue to disperse the information. This step is crucial in establishing cash flow for the facility so that it can fund its own activities without being entirely dependent upon the sponsors and their ability to place contracts with the University.
- Immediately purchase several relatively low cost items which can have a drastic affect on whether the laboratory is operated in a safe manner. These items include hearing protection for the operators and visitors, eye protection, a first aid kit,

precautionary signs to keep people out of the area while testing is in progress, lab coats to protect personal clothing and a general assortment of tools and supplies so that the right equipment is available when needed. This assortment includes several sizes of fuses, different sizes of wire and an assortment of hand tools.

- Complete the development of operating procedures so that operators become accustomed to following them on a routine basis without having to "ad-lib" because applicable procedures are not finished. Learning to "make do" encourages personnel to bend the rules rather than follow the guidance of those who have gone before them. Also, develop maintenance procedures to remind operators that periodic inspections are necessary and to ensure that all of the equipment remains in good working order.

Since these recommendations benefit everyone, the sooner they can be implemented, the better for all concerned.

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APPENDICES

Appendix A

Motor Systems Resource Facility

Business Plan

Prepared

March 1, 1996

Table of Contents

Executive Summary

For over ten years, Oregon State University has conducted motor testing and evaluation on a variety of different types of motors and drives less than 30 hp. In the early 1990s several people began to notice the need for a regional testing facility to conduct independent evaluations of competing technologies, to assess the impact of installing new products into existing systems, to research new problems that were surfacing and to educate users in the subject of motors and their controllers. An advisory group was assembled with representatives from the electric utilities, motor manufacturers and university faculty to design and build a testing facility capable of meeting these needs. The name selected for the facility is the Motor Systems Resource Facility (MSRF).

This consortium of government, industry and university personnel provided the funding for the project. Oregon State University was selected as the site of the facility because of its reputation in this field and to allow access to University resources. The University provided the building to house the facility, technical support and student workers. In exchange, it receives a state of the art testing facility for use by students and faculty, and the students receive practical experience using equipment they are likely to encounter after graduation. The other sponsors gain access to a modern testing facility which would not have been built without their contributions. This Business Plan documents the roles of each party, describes how the MSRF will be operated and plans for future expansion.

The sponsors were willing to provide the capital funding to build the facility, but wanted it to become financially self-sufficient. Since there are no similar facilities in this region, it was difficult to predict what services would be required by local companies. Therefore, a major design consideration was to make the facility extremely flexible so that it would be capable of testing a wide variety of products under actual and simulated operating conditions. Motors, generators, drives and instrumentation can be tested up to 300 hp, with the capability to expand to 500 hp or beyond when needed. Components may be tested individually or as systems with control and data acquisition functions performed via computers. The electrical power drawn by the motor is converted back to useful energy and returned to the electric utility grid to reduce system complexity and increase operating efficiency.

The MSRF offers testing to recognized standards, such as IEEE 112 for induction motors, or specialized testing to meet the particular needs of each customer. Independent evaluations of new products and competing technologies assures unbiased results. Consulting services are offered in the areas of failure analysis, technology upgrades and personnel training. Research facilities are available to individuals and companies interested in testing new ideas and concepts which are beyond the capabilities of their current facilities. All of these services are available to the public in a timely manner and for a reasonable price. As the facility becomes more fully utilized and new technologies are developed, upgrades will be made to the equipment and services to ensure that they remain state-of-the-art and continue to meet the needs of the customers.

I. Vision/Mission

1. Description of Need

The use of electric motors in all applications has been drastically affected by the implementation of power electronics in motor control systems. The resulting improved performance and greater versatility has allowed designers to use standardized induction motors in many applications which previously required specially designed motors. This reduced demand for motor design engineers has forced many universities to eliminate their motor design and testing capabilities. Oregon State University (OSU) is one of a very few which still have active programs in this field.

For several years the OSU faculty and their industrial advisors have recognized the need for a regional testing facility with broad capabilities to:

- research new and innovative designs,
- independently evaluate manufacturer's product claims,
- investigate problems with current designs, and
- provide hands-on training for students specializing in the "Power Area" of Electrical Engineering, and for the continuing educational requirements of engineers in industry.

In the past, the testing and research at OSU was limited to less than 30 horsepower with a nominal voltage of 230 volts. For data acquisition, a specialized system of power, voltage and current transducers, and torque and speed mechanical transducers had been developed with a sampling mechanism to enable storage, and finally, processing by custom software with a computer. Recent developments in computer interfaces (i.e. the concept of Virtual Instrumentation software) and the new "power analyzer" instruments have made this technique obsolete. In addition, such approaches were not desirable when conducting a comprehensive testing program which would be of interest to most industrial companies, and a more flexible testing facility with higher ratings was needed.

2. Charter

As a result of this need, a group of advisors and sponsors was assembled to help overcome the challenges. After two years of negotiations and changing priorities, the group settled on the charter for the facility described below.

Mission Statement

It shall be the Mission of the Motor Systems Resource Facility to address the following issues:

- Promote the effective and efficient use of electric motors, drives, and generators. Solve related problems pertinent to the interests of the member utilities and their customers.

- Act as a vehicle for the professional development of the staff, particularly students and researchers at the University.

- Develop resources of relevant skills and information which will be disseminated to industry.

Seven principle activities were identified for the facility. They are:

1. Test evaluation and analysis;
2. Assessment of alternative technologies;
3. Research on advanced machines and converters;
4. Assessment of power quality (and its control);
5. Training in contemporary equipment and techniques;
6. Compiling a knowledge base;
7. Communication of all of the above;

3. Objectives of Each Participant

The bulk of the funding for this project was provided by the Electric Power Research Institute (EPRI) through the Tailored Collaboration Program. EPRI recognized the need for a regional motor and drive testing facility available to EPRI members and their customers. EPRI sponsors a number of service centers throughout the country which act as referral centers when customers pose questions in their area of specialization. However, to continue their operation EPRI must provide annual operating funds. The goal of this facility is to become self-sufficient by charging for its testing, educational and research services. In addition, this laboratory will provide EPRI member utilities and their customers access to motor and drive design, performance and testing information gathered through operation of the MSRF.

The U.S. Department of Energy (DOE), the Bonneville Power Administration (BPA) and other sponsors (including Pacific Gas and Electric, Puget Sound Power and Light, Marathon Electric, Kenetech and Superior Electric) also recognized the need for a regional motor testing facility. Their goal was to build an independent test facility capable of assessing new and/or competing motor and drive technologies. This facility would be capable of testing new electrical machine related technologies to determine if the manufacturers' claims were correct, to conduct side-by-side testing of motors under actual loaded conditions and to present the results of such testing in a clear and unbiased manner. Further, this facility must include the latest technology and retain the flexibility needed to incorporate new technologies as they are developed. By constructing the facility on a university campus, the users would be able to have access to the extensive resources of the university faculty, technical staff and equipment, and be able to keep abreast of developing motor and drive technologies.

The goals of Oregon State University matched well with those of the other sponsors. OSU would be able to construct a state of the art facility in a climate of decreasing funds for capital projects. This facility would expand the capability to test motors from the current 30 hp limitation up to 300 hp initially, and to a higher value at a later date if needed. In addition, an automated instrumentation and control system would be added to allow more efficient and accurate measurement of system performance. This facility would be available for other researchers in the University, not necessarily those working exclusively on motors and drives. Students would now have systems representative of what they would encounter in industry, thus making the students' education more valuable to them. Using student workers in the center provides them with hands-on experience and allows the center to operate at substantially lower cost than similar facilities built in the private sector. This feature is important since the University also desires that the center be operated in a break-even manner.

4. Unique Capabilities

The advisory board recognized that the center must possess capabilities beyond those of similar facilities and beyond those that can be quickly and easily installed in an existing facility. The MSRF had to test motors which were representative of those used in industry today, and for years to come. Unlike the current limitation of 30 hp, this facility must be able to test motors above 100 hp, and in a manner representative of how the motor would be operated. The path chosen was to use a regenerative system capable of placing a mechanical load on the motor to be tested and converting that energy back to 60 hz power which could then be returned to the electrical service grid. This method had several benefits which included reducing both the electrical demand and energy consumption by approximately 90%, eliminating the need for fluid and air systems to dissipate the heat generated, and providing a means to rapidly vary the load on the motor, thereby simulating a variety of loads in industry without requiring hardware changes.

This facility is designed to use modern personal computer (PC) technology to allow rapid and inexpensive upgrades as new developments are made. The system does not require highly specialized programming skills and measurements can be taken simultaneously throughout the entire system, eliminating the errors caused by asynchronous sampling. In addition, data is collected by the computer using commercially available data acquisition software to reduce data logging errors. This also produces a documented record of each test which can be incorporated into test reports, archived and examined later if questions should arise. As tests are completed, the results will be added to a database which is available to facility users, designers and others.

The projects that can be undertaken in the MSRF are extremely broad based due to the range of expertise and experience of the personnel involved. Using university faculty and technical staff, needed skills can be made available in both electrical and mechanical disciplines in the areas of design and synthesis, simulation and analysis, testing and education.

II. Market Analysis

1. Facility Users

The wide range of potential customers has been summarized into three general categories (Routine, Frequent, and One-Time) based on their projected usage of the facility. These categories will be used when allocating personnel and equipment hours, projecting revenue, designing facilities, developing procedures and marketing the center's services. A more detailed breakdown is contained in Table 1.

- Routine Users: This group consists of users conducting periodic testing to predict equipment performance and durability, collecting baseline data for new systems being developed and by university faculty for teaching purposes.

- Frequent Users: This group will include repeat customers who's needs vary depending upon their customers' needs or changes in their business. This group will require similar services for each test, but will be on an irregular schedule with varying degrees of urgency. This can include a manufacturer who desires to randomly test samples of hardware that he makes or that is delivered by a vendor. Motor manufacturers and users of all kinds can test suspect hardware in a local facility convenient to their operations and utilities can determine actual efficiency for use in motor rebate programs. This group can also include trade associations and government organizations interested in independent evaluations of new products.

- One-Time Users: These customers will experience a need for testing services for which they do not have the personnel, facilities or equipment available. Rather than acquiring these resources, they may find it quicker and less expensive to use this facility. Potential customers include end users which operate a large number of similar motors for which they are considering modifying components or replacing them with improved products. This could also include inventors, product developers, or potential technology investors interested in evaluating prototype devices or unusual applications of existing hardware and software. Although members of this group are more likely to use the center again once they have successfully dealt with it, their testing needs will generally be unique to their business and will require special considerations for each use. For example, determining the cause of system failure or evaluating different products.

Each of these groups has different requirements concerning the data to be collected, the extent of testing to be performed, the urgency of the testing and the amount of money they can afford to spend on testing services.

	Independent Evaluation	Standards Testing (IEEE, NEMA)	Performance Testing	Technology Analysis	Failure Analysis	Investigate Abnormalities (Power Qual.)	Hands-On Instructio n	Consultation
Routine								
Educational Groups							X	
Small Motor Manufacturers		X	X	X	X	X		X
Small Drive Manufacturers		X	X	X	X	X		X
Motor Repair Shops		X	X		X	X		X
Frequent								
Major Motor Manufacturers	X	X						
Major Drive Manufacturers	X	X						
Utilities	X	X	X	X	X	X	X	X
Trade Associations	X	X	X	X	X	X	X	X
Industrial Mfgrs. (End Users)	X	X	X	X	X	X	X	X
One-Time								
Inventors		X	X	X	X	X		X
Research Groups	X	X	X	X	X	X		X

Table 1 -- Market/Service Grid

2. Customer Inquiries

Prior to operation of the facility, several organizations became aware of the MSRF and began to investigate its capabilities. These individuals were provided with information via telephone and fax, as well as brochures describing the facility's operation. This section is included to demonstrate specific areas where potential customers have expressed a need for services. The companies' names have not been included in this document because their identities are not important for this discussion.

- One group which includes an electric utility, motor manufacturer and an industrial customer has chosen the MSRF to conduct an evaluation of two motor and drive systems. One is a standard induction motor with an adjustable speed drive and the other a switched reluctance machine with a speed controller. These machines will be tested under various speed and load conditions to demonstrate their operating characteristics prior to being installed in an industrial facility.

- Two electric utilities have contacted the MSRF and expressed interest in testing motors to determine their actual operating efficiency. These utilities have rebate programs which reward customers for upgrading their motors and drives to more efficient models. The size of the rebate is based on the amount of energy saved and thus can vary significantly when using nominal rather than actual efficiency. To ensure that their clients are getting what they paid for and that the utility will benefit as desired, they would like to have independent testing to build up a database for the replacement motors.

- A major motor manufacturer expressed interest in testing large (500 hp) motors under load at this facility. This company is able to perform no-load testing locally, but must ship the motors out of this region to collect data under loaded conditions. They viewed the OSU facility as being potentially quicker and less costly than shipping it to their own facility.

- A local motor distributor and repair center expressed interest in using the MSRF to test a motor before and after being rewound in their shop, using standard industry practices. Their desire was to show that standard and premium efficient motors could be rewound without adversely affecting the efficiency or performance of the motor. Some of their customers had expressed concern that a rewound motor was somehow inferior to a new motor. Their intent was to test a new motor, take it back to their shop to be refurbished, and then to have it tested again. They felt that this would help assure their customers that they were getting a quality product which met industry standards and performed nearly as well as a new motor of similar design.

- A manufacturer of energy conversion devices has designed and built some units to operate as motor drives. His current facility does not have the fixtures or utility power available to test units beyond a few kilowatts. Their desire is to test units before delivery to the customers' sites and to collect data to aid in their design process.

- A similar company builds generators powered by diesel and gasoline engines. They expressed interest in testing both their electric generators and the full systems under loaded conditions.

In each of the above cases, the facility was able to meet the testing requirements established by the potential customer and exceeded the customer's own capabilities. This shows that the flexibility that was designed into the MSRF met its objectives and should meet the needs of its future customers for some time to come.

3. Sales Forecast

As previously discussed, the anticipated sources of income will be derived from the three types of facility users: Routine, Frequent and One-Time. Each category of users is expected to have its own testing requirements and price sensitivity for the services offered. The most price sensitive will be those on a "shoe-string" budget, such as independently funded inventors, and those seeking routine testing services for induction motors under 50 hp. Since these relatively small motors have become a commodity item in recent years, the cost has decreased accordingly making the cost of testing greater than the cost of the motor in some cases. Therefore, failure analysis and routine efficiency testing in this size range is not likely.

The least likely to question the cost of testing will be those organizations involved in design and testing of new specialty motor systems. These tend to be longer term projects involving multiple organizations and using professional personnel at relatively high hourly rates. The MSRF has the advantage of using primarily student workers at a very reasonable hourly rate. However, the lead time to participate in these programs is usually one or more years due to the steps involved in adding the testing to the budget process, and therefore cannot be expected to contribute significantly to the workload of the MSRF for at least two years.

Sales projections are based on the following assumptions:

1) Initial sales will result primarily from referrals by sponsors and advisory board members.

2) No training classes will be given during the first year.

3) Student workers will be added as needed to support the workload of the MSRF, thus avoiding a shortage or surplus of labor.

Organizations will be notified of the opening of the MSRF using the methods discussed in Section VI. This will include brochures, press releases, technical conference presentations, technical papers, computer Web Pages and video tapes describing the facility's capabilities. Potential customers will be offered tours of the facility and will be given explanations of the benefits of using this facility versus building their own.

In addition, some of the MSRF's sponsors have expressed interest in notifying their customers of the facility's existence and capabilities. These organizations include trade associations and utilities interested in evaluating new products and improving system efficiency. Notifying their clients provides a service to them as well as assisting the MSRF in attracting new customers.

The rate structure which has been established takes into account the differing needs of the customers and encourages early use by the sponsors and their customers. The subject is covered in greater detail in Section VII. A sample invoice is shown in Appendix A.

By setting lower prices for the sponsors in the first two years, the MSRF is allowing them to recoup some of their investment, while at the same time encouraging them to start using the facility before this benefit disappears. This method should provide greater initial sales for the center than by using a uniform pricing policy. The risk of discouraging non-sponsors from using the facility is relatively small since this is a capability that they do not possess and the difference in cost is certainly less than other alternatives available to them.

The sales goals established are shown below.

Service Offered	1rst Year	2nd Year
Research Projects	$ 25,000	$ 40,000
Evaluation & Performance Testing	$ 30,000	$ 40,000
Standards Testing	$ 10,000	$ 20,000
Failure Analysis/Evaluate Abnormalities	$ 10,000	$ 15,000
Training	$ 0	$ 10,000
Total	**$ 75,000**	**$125,000**

Table 2 -- Yearly Sales Goals

These sales goals were set based upon the following information.

- Past Sales -- In each of the last two years, testing of electric motors and drives at OSU has exceeded $30,000 while the facilities were limited to 30 hp. By upgrading the capability to 300 hp and improving the efficiency at which the tests are performed the center is now able to test a wider range of equipment and serve more users in the same amount of time. Using the marketing strategy outlined in Section VI the sales goals listed above are certainly achievable.

- Workload at similar centers -- It is difficult to project sales for this center based on the workload in similar centers because of the differences in capabilities, local industries and funding sources to support the centers. For example, the Industrial Electrotechnology Laboratory on the NCSU campus is funded by local utilities so that its services are free to the utilities' customers. From 1993 to 1994 they performed over 300 tests on motors. Since the center at OSU must be financially self supporting, the services cannot be offered free of charge and demand is expected to be significantly less.

- Revenue needed to support the MSRF -- A detailed list of expenditures is contained in Section VII. These figures reveal that the minimum expenses to merely remain open are approximately $50,000 per year. However, the long term success of the MSRF depends upon the marketing efforts over the first two years and therefore the expenses are expected to be higher than this minimum amount. The sales goals listed above exceed this minimum funding level and allow for growth of the facility.

4. Future Needs

The facility now has the capability of testing motors on several small test beds up to 15 hp. In addition, the 300 hp test bed is also operational. In order to provide the most accurate measurements and make cost effective use of the equipment, it is desirable to test motors close to the maximum rating of the test bed. From a practical standpoint this limits the use of the 300 hp test bed to motors above 60 hp. Although smaller motors can be tested, they usually require special mounting and different instruments than those normally installed. Building another test bed rated between 60 and 100 hp would provide the center with greater flexibility in the use of the equipment thereby allowing one test to be set up as another is being conducted. The other advantage would be more accurate measurements in the 15 to 60 hp range. Based upon inquiries to date, the addition of a test bed in this range would then cover most of the needs of potential customers.

Based upon the success the MSRF is having with recirculating the power, rather than simply dissipating it as heat, it may be possible to increase the capacity of the facility beyond the original design limitation of 500 hp. The overall electrical losses on the 300 hp test bed are less than 15% at full load, with less than 5% THD on the power returned to the electric grid. If a converter with suitable characteristics can be found and there is sufficient demand to justify upgrading the capacity of the laboratory, this may be done in a later phase.

Further upgrades can be made to the laboratory's capabilities based upon the needs of its customers. They can include providing DC voltage at higher power levels, programmable power supplies, vibration and temperature measurements and possibly 4160 VAC. In addition, as new instrumentation becomes available the center must keep up to date to remain a viable resource center. Eventually, the MSRF may undertake the administrative burden of becoming certified so that its results will be acceptable to all parties.

III. Competitors

The term "competitors" is used in this section to denote similar facilities which are currently operating and serve as a basis in determining whether duplication will exist. Each of these facilities is unique, with different missions and areas of expertise. In some cases a price comparison was made to ensure that the MSRF rates are in-line with those of other facilities. It is not the intention of the MSRF to take work away from the other centers, but rather to provide services to customers which were not previously available or were not practical for a number of reasons. Collaboration with other facilities is anticipated and highly desirable as a means of reducing expenses and combining resources to provide enhanced capabilities beyond that of a single center.

1. Industrial Electrotechnology Laboratory (IEL)

This laboratory is located on the campus of North Carolina State University and was established by the N.C. State University College of Textiles and N.C. Alternative Energy Corporation. It receives funding from local utilities which allows it to offer many of its services for free to the utilities' customers. This facility tests motors, drives, lighting and electrical drying systems. Its size limitations are shown in the information contained in Appendix B.

2. Laboratoire des technologies electrochimiques et des electrotechnologies (LTEE)

LTEE is affiliated with the Quebec Hydro Electric Utility and is located in Quebec, Canada. The laboratory serves industrial and residential customers in electrochemistry, industrial plasmas and electrotechnologies. A major emphasis of the center is determining the technical viability of different technologies, particularly in the areas of energy savings and increased energy efficiency to make industries more competitive. Part of this mission involves testing motors and their controllers for efficiency and harmonic analysis. The capabilities of their three motor test beds are shown in Appendix B. The two largest units use a water brake and an eddy-current brake thereby limiting load changes and precluding regeneration of electric power. This means that all of the motor's power must be dissipated as heat which would become quite costly for extended testing of large motors, although that LTEE is serviced by Hydro Quebec at no cost.

3. Power Electronics Applications Center (PEAC)

This laboratory is located in Knoxville, Tennessee and is affiliated with EPRI and the University of Tennessee at Knoxville. It operates as an independent testing center with its own staff. The testing focuses on power electronic converters, rather than motors. By using a 100 KW programmable power supply they are able to generate specific waveforms and study the response of the converters to conditions such as voltage droops and harmonics. There ability to test entire systems and particularly motors is limited by the size of their power supply and the lack of test beds on which to mount the motors.

4. Motor Manufacturers

When it comes to testing and failure analysis of motors and drives, the manufacturers have a distinct advantage over this and other independent centers. Namely they designed, built and originally tested the motors. They have all of the fixtures needed to mount the motors and all of the facilities to perform load testing. They employ a well trained and stable workforce as opposed to student workers. If they come across a problem during testing, they have all of the facilities needed to repair the motor, such as replacing bearings, rewinding stators and balancing rotors. Their disadvantages include testing and repair facilities that are not located in this area. This imposes added shipping costs for other than testing of new motors. Their worker's salaries are higher than those of the student workers in this center. Also, customers desiring independent evaluations or comparisons with competitors' products would normally go elsewhere for testing.

The rates charged by the motor manufacturers for testing varies considerably depending upon the type of testing to be performed. One company's published rates for testing under laboratory conditions according to IEEE 112 are shown below.

Motor Size	Standard Test	Witnessed Test
<15 hp	$1334	$4669
15-250 hp	$2001	$5336
250-500 hp	$4892	$7560

These are list prices with the cost to a large volume customer discounted up to 50%. The MSRF rates listed in Table 6 compare favorably to those above and there is no premium charged for customers to witness the testing.

IV. Service and Testing Strategy

1. Existing Test Centers

The other existing test centers appear to serve their markets well. They focus their attention on particular areas such as power electronics and energy efficiency studies and serve customers primarily in their geographic region. However, none of the other centers is located in this region and many of the local customers are not interested in sending their equipment to distant sites to be tested. This would involve added costs for transportation, time delays in shipping and no continuing benefits to this area as with a facility in this region.

2. Capabilities of the MSRF

This center is a local resource, not previously available to individuals and companies in this area. This facility is truly unique on the west coast due to its capacity and testing configuration. It has been designed to meet the needs of current customers and to be flexible enough to adapt to the needs of future customers. The center employs state of the art technology for testing, instrumentation and data analysis. The center acts as an information resource for education, research and standardized testing. As tests are completed, the results are added to a database for comparison with other tests or further analysis. To be successful, this center must be responsive to the customer's needs, including timely approval of a contract. To help expedite the administrative processing a two page service and testing agreement has been developed by the center. A copy of this agreement is included in Appendix A. This document can be approved in one day versus the several weeks it took for previous contracts. Such streamlining of administrative procedures is expected to be of great benefit to the center and how it is perceived by potential customers.

V. Facilities and Operations

1. Organization

The MSRF is currently operating as an entity within the Department of Electrical and Computer Engineering at OSU. As such it must comply with State, University and Departmental requirements. This business plan serves to document how the MSRF will be operated and plans for future expansion. The operating procedures are being developed to ensure the safety of the workers and equipment as well as the accuracy of the test results. Eventually the facility may be organized as an independent center operating under the State of Oregon Board of Higher Education.

2. Advisory Board

To help turn this dream of a regional testing facility into a reality, an advisory board was formed in 1993. The board members consisted of university professors, utility members and industrial participants. Through a series of meetings, a list of basic capabilities was established for the center and a draft charter was developed. The guidance from this board served as the basis from which the administrative procedures used by the MSRF were developed.

3. Staffing

The Director of the MSRF also serves as the Chairman of the Energy Systems Group within the Electrical and Computer Engineering Department. He is available on a part-time basis to provide direction to the staff and to interface with customers and sponsors. His responsibilities include long term planning as well as daily operation of the MSRF.

The secretary is available on a part-time basis from the Electrical and Computer Engineering Department staff. Her duties include preparing and transmitting correspondence to customers and suppliers, maintaining test procedures and preparing test reports.

The technicians and other university personnel are available on an as-needed basis to supplement the MSRF staff. They consist of mechanical, electrical and electronic technicians capable of maintaining, modifying and updating the equipment as needed to perform the desired tests. Other professors and staff members from different disciplines are also available as needed when questions arise which are beyond the capabilities or expertise of the MSRF's permanent staff.

The normal operation of the laboratory is performed by graduate students in the Energy Systems Group of the ECE Department. These students are enrolled in Masters and PhD programs and gain valuable experience while performing the tests. Initially two graduate students were assigned to oversee construction of the facility. Once the MSRF became operational, these students maintained and operated the equipment while other students established the technical requirements and conducted the tests. All of the students will benefit from using state-of-the-art equipment and are expected to resolve issues which arise during testing. Observations made during the tests can form the basis of, or be included in, the students' technical publications, such as theses and conference papers, unless prohibited by confidentiality agreements.

4. Capabilities and Resources

Building and operating such a facility was recognized as a major undertaking for the ECE Department. Funding had to be obtained for the design, construction and continued operation of the facility. The laboratory had to be designed to be state-of-the-art to attract interest and funding for the project. The facility had to be versatile enough to accommodate a wide variety of testing needs by meeting current and projected requirements, without being prohibitively expensive in this era of reduced funding for higher education. It was also recognized that the MSRF's operational costs would have to be funded by its activities. To reduce its dependence on any one sector, the MSRF would have to appeal to a number of potential customers.

The MSRF was designed with input from university faculty, staff and graduate students, members of the advisory board and finally documented and certified by an engineering consulting firm. The facility is designed to test motors, generators and control systems up to 500 hp, with the capability to expand to 1000 hp in the future if the need arises. The instrumentation is PC based to allow simultaneous collection of data from multiple sources, periodic upgrades as newer hardware and software become available, and automatic data acquisition to minimize human error in reading instruments. Additional stand-alone instruments are available for local measurements and to calibrate and verify measurements taken by the PC based system.

The MSRF is also intended to be a resource for parties interested in learning more about motors, generators and drive systems. By calling the MSRF, individuals and companies can learn what resources the facility has to offer, documents published on the subjects and referrals to other organizations which may be able to assist them.

5. Process Description

This process is illustrated in Figure 1. The service and testing function begins when a potential customer initiates contact with a staff member. Regardless of how the individual became aware of the facility, they will be inquiring by telephone, fax, letter or email about how the facility can meet a need that they have. The staff member will attempt to collect as much information as possible about this need to determine if the MSRF can be of assistance. If it is clear that the center does not have the facilities or expertise required, the person will be referred to other facilities better suited to help them. If the customer desires further information, they will be referred to the web page for general information which is immediately available to them or brochures will be mailed to them. Specific questions will be answered by telephone, fax or email as appropriate. Above all the customer must feel that their inquiries are being handled in a professional and timely manner, otherwise they will feel that this is how their project will be handled.

The information sent to the customer may include the tri-fold brochure for general information, the new color brochure and any single page inserts which are appropriate for the type of testing to be performed. If standard testing is anticipated, a sheet listing these prices and a copy of the Service and Testing Agreement will be included along with a cover letter inviting further communication.

If the customer then chooses to use the MSRF, they may send a letter requesting the desired services, submit the Service and Testing Agreement along with the Work Order or request that the MSRF initiate the Agreement. In any case, a Service and Testing Agreement will be prepared which includes a Work Order describing what services are to be performed and the price to be paid for these activities. This amount may be a fixed price, as for standardized testing, or an hourly rate for use of the facilities and personnel with a not to exceed value established. The Work Order is unique to each job and specifies what work is to be done, the responsibilities of each party, handling of proprietary data, the schedule of activities including items to be coordinated with other parties and any critical milestones or decision points. After both parties agree to the scope of work and price, the Agreement is signed by the customer, the Director of the MSRF and the University Contract Administrator. The approval by the University is expected to take no more than one day thereby ensuring timely response to the customers' needs.

If the testing requires assets not available in the MSRF, the Director must determine how to acquire these items. For example, hardware may be loaned from other University departments, rented from commercially available sources, fabricated, purchased or supplied by the customer. This decision will be based primarily on the availability of the item and its anticipated need for future testing. This process will be used for specialized tools, drives, power supplies, instrumentation, mounting fixtures and software.

After the Service and Testing Agreement has been approved, the Director assigns one or more student workers as Test Directors to organize and conduct the tests. The Test Director then gathers the equipment, prepares the test procedures and schedules the time needed for the testing. The equipment is operated by the student workers assigned to the laboratory to ensure that personnel and equipment safety procedures are followed. The Test Director ensures that the technical objectives and data collection requirements are met. After the testing is completed, the Test Director analyzes the data, prepares the data for archival storage and prepares the final report to be delivered to the customer. A copy of the final report is maintained in the MSRF's data library along with a copy of the raw data collected and any supporting information. The Director oversees this entire process ensuring that the technical and contractual requirements are met in a safe and efficient manner.

Upon completion of the testing, or as agreed upon in the Work Order, an invoice similar to the one shown in Appendix A is delivered to the customer. In addition, customer feedback is sought via telephone, fax or letter to see if their needs have been met and to solicit recommendations for improvement. Obtaining this feedback is absolutely essential if the facility is to continue to develop and meet the needs of its customers for years to come.

If the customer desires to conduct research testing in the laboratory, the process described above is modified slightly. The primary characteristic which determines whether the testing is classified as research is if there is an intent to develop intellectual property, which then belongs to the MSRF, or the customer, or is shared between the parties. Instead of using the Service and Testing Agreement described above, a Research Proposal containing a Statement of Work is submitted to the customer by the MSRF and is approved by the customer, the Director of the MSRF and the University Dean of Research. Generally, these Research Agreements are unique to the testing to be performed and therefore take longer to negotiate than standardized testing. They may contain special provisions for data collection, how the testing is conducted, handling of proprietary data, etc. This testing may span several weeks or months with several decision points based upon the results achieved in preceding steps. In nearly all cases, the research testing will be priced based on the hourly rates of the test center and personnel involved.

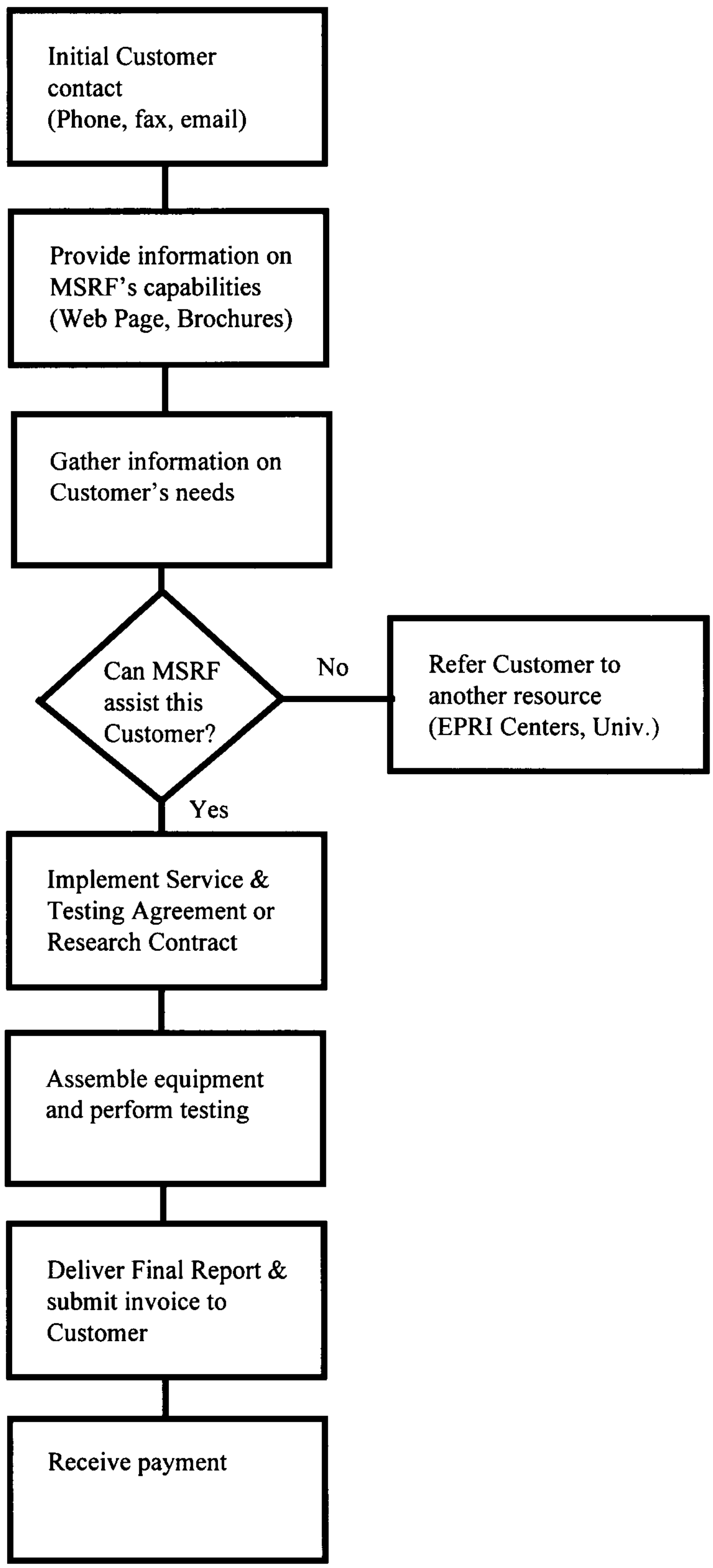


Figure 1 -- Flowchart of Testing Process

VI. Marketing Plan

1. Objectives

The purpose of the marketing effort is to notify potential users of the existence of the MSRF and of its capabilities, particularly during the first year of operation. This means that, as a minimum, each of the groups identified in the Market Service Grid must be notified. A variety of advertising methods have been chosen to ensure each area is covered and that multiple contacts are made. Some steps have already been taken to notify potential users, and other activities have been planned.

Event	Date
Tri-fold Brochure Printed and Distributed	April 1995
Video Tape Describing the Facility	May 1995
Motor Challenge Video Teleconference	May 1995
IEEE/KTH Technical Paper and Presentation in Stockholm	June 1995
Information Folder Assembled and Distributed	August 1995
DOE Motor Challenge Conference Presentation in Chicago	September 1995
WWW Page Established and Linked to OSU Page	January 1996
Cement Industry Workshop in California	February 1996
Link WWW Page to WSEO and EPRI WWW Pages	February 1996
Announce Facility & WWW Address on "Power Globe"	March 1996
Open House Ceremony for MSRF With Invited Guests	(TBD) 1996
Notify Local IAS Chapter of Opening of MSRF and Capabilities	July 1996
Improved Video Tape Describing the MSRF	September 1996
Prepare Color Brochure of MSRF	October 1996

Table 3 -- Marketing Milestones

2. Brochures

The first advertising material prepared for the center was a tri-fold brochure in Appendix A. This was prepared as a low cost method of communicating the mission and capabilities of the center to interested parties. This brochure was prepared on a word processor and copied onto colored paper. Since the facility had not been constructed, photographs were not available. Instead text and a system diagram were provided. This brochure was provided to participants in the Motor Challenge Teleconference hosted at OSU in May 1995 and to other parties inquiring about the MSRF. This brochure was prepared quickly, was easily updated, and fulfilled its objectives well.

Now that the MSRF has been built, photographs will be taken showing the equipment configuration and testing in progress. These photographs will then be incorporated into a color brochure suitable for distribution to potential customers. In addition, single page inserts will be prepared from time to time which can be passed along with the brochures. These inserts will discuss new equipment after it is installed or target particular groups with specialized needs. They can also be used to more thoroughly explain testing capabilities if confusion exists and to announce new services which may be needed at a later date.

3. Videos

A six minute video tape was prepared in May of 1995, primarily to support the Motor Challenge Teleconference hosted at OSU. This tape shows some of the equipment before it was mounted in its permanent configuration. New videos can now be prepared which show the entire facility in operation and describe its capabilities and components. A three minute video will serve as an introduction to the MSRF describing its location, purpose and a brief overview of its capabilities. This video will be useful for press releases, general information at conferences and initial exposure to industries in this area.

Another video, ranging from 10 to 15 minutes, will be prepared which describes the mission, staffing, and range of resources and services offered by the MSRF. The equipment available in the laboratory and its capabilities will be covered in much greater detail than in the first video. This video will be useful for explaining to new customers the degree of flexibility designed into the MSRF and how it can meet their particular needs. It will be useful to mail to potential customers, for impromptu presentations to visitors and for presentations to area professional organizations and technical training classes, such as those offered by local utilities and manufacturers.

4. Conferences and Papers

Some presentations have already been made to professional organizations describing the plans for the MSRF. Now that the facility is operational, papers can be presented describing the success of the systems involved and plans for the future. These papers will focus on the unique capabilities of the MSRF and the flexibility to meet future needs, whatever they may be. In addition, as more tests are completed the results can be published as a compilation drawing conclusions based on several tests performed under varying conditions rather than as single, stand-alone tests.

As more results are obtained, more information can be presented, which will result in more exposure and greater interest in the MSRF and its activities. Therefore, these presentations, seminars and technical papers will serve as important marketing tools for the MSRF and its projects. Initially, these papers must focus on the same issues and reinforce the same points so that the audience does not get confused and think that they are hearing about several different facilities. It must be one clear message being distributed as widely as possible to the target market.

5. Press Releases

Press releases will be timed to coincide with major activities involving the MSRF. The first such event will be the Open House which will occur in 1996 following the successful completion of some initial projects. So far a date has not been established which is convenient for all of the sponsors. This event will involve representatives from each of the sponsors as well as invited guests from local utilities and industries. This will be the first opportunity that most people have to visit the center and see what its capabilities are. The general public will be notified of the event through press releases to newspapers and television stations. Other guests will be invited by a mass mailing.

Several key points will be distributed to the media in a press release to communicate the messages clearly and to avoid potential confusion. Namely, that the MSRF is:

1. A resource to area companies and individuals.
2. A teaching tool for University faculty.
3. A research facility for faculty, staff and students.
4. Available for all to use.
5. Self-supported by charging for the services it offers.

These press releases will be repeated periodically to ensure that potential customers are aware of the facility and its capabilities through the standard news media. In addition, University alumni will be informed of the MSRF's progress through alumni publications. This group may provide additional business for the laboratory as well as a source of equipment donations as their companies update existing systems.

6. World Wide Web Pages

There is a major revolution taking place in the business world regarding advertisement, communication and literature searches. The World Wide Web (WWW) is frequently being used to make initial contact between businesses needing services and those offering services. Within a few minutes of sitting down at a computer terminal, a person can search for several key words and locate businesses of interest. During this same period the person can view a picture of the product, review the history of the company, send and receive responses to questions, and even place an order to have the product delivered the next day. The technology and communication systems to make this possible has only been available in recent years. As the costs continue to drop, more and more people will be using this service on a daily basis.

To take advantage of this new medium, the MSRF now has a WWW Page which describes the history of the facility, displays photographs and resumes of the staff members, describes the capabilities of the MSRF and allows a viewer to take a virtual tour by seeing pictures of the facility from several vantage points. Interested parties are provided with names, addresses and phone numbers of people to contact as well as an email address to respond to. This page has been linked to other Web Pages, such as those maintained by the Washington State Energy Office, EPRI, OSU and ECE Department. Links to other frequently visited pages will be investigated and made when appropriate. As this is a very low cost method of communication which can be updated frequently to meet the changing needs of the customers, it should be used as extensively as possible.

VII. Financial Plan

1. Capital Requirements

The funding for Phases I and II (totaling $575,000) was provided by a consortium lead by the Electric Power Research Institute (EPRI). EPRI both originated funding and provided matching funds through its tailored collaboration program with member utilities. In addition, an award was received from the U.S. Department of Energy's University Instrumentation Awards Program for $240,000 to supplement the instrumentation and data acquisition equipment. The conceptual design was originated by OSU faculty and students and was documented and engineered according to appropriate codes by a consulting firm.

Oregon State University provided the building in which the facility is now housed. Previously this laboratory was used to evaluate high voltage transmission lines (over 100,000 volts), but at low power levels. In order to provide the higher power required by the large electric motors to be tested, the facility had to have extensive modifications. A dedicated power line was added by the local utility to allow running larger loads than the building electrical system would support and to minimize the possibility of adverse affects on or caused by other electrical power users within the building. Other building modifications included remodeling a storage area to act as the control room and adding a loading area to support handling of large equipment.

These modifications and the installation of the facility's instrumentation were performed by a combination of OSU facilities services, contractors and graduate students. The motor control centers, instrumentation, auto transformers, power converter and dynamometer were all purchased from vendors and installed in the center. To allow testing a wide variety of motors with differing frame styles, unique test beds were required which were designed and fabricated in the OSU support shops.

2. Operating Expenses

The project sponsors recognized the need for, and were willing to provide, capital funding to allow building the test facility. However, they did not wish to incur the long term financial liability associated with having to fund the operating costs of the MSRF. Therefore, it was decided at an early stage that, unlike most university facilities, this one should be designed, built and operated such that its activities become financially self-supporting.

Table 4 lists the operating expenses which have been budgeted for the MSRF. This represents primarily fixed costs, with variable costs for the labor to perform the testing being in addition to these amounts. Since the variable costs are highly dependent upon the number of and sophistication of individual tests, they have not been included in this plan.

MSRF OPERATING EXPENSES

	Normal Operating Funding	Minimum Subsistence Funding
VARIABLE OVERHEAD		
Power Usage	$ 2,500.00	$ 1,000.00
Technicians @0.2 FTE	$ 10,400.00	$ 5,200.00
Student Workers 2@0.5 FTE	$ 24,480.00	$ 16,400.00
FIXED OVERHEAD		
Director @0.5 FTE	$ 45,000.00	$ 10,000.00
Secretary @0.5 FTE	$ 20,000.00	$ 10,000.00
Office Equipment	$ 3,000.00	$ ---
Office Supplies	$ 5,000.00	$ 2,000.00
Lab Equipment	$ 5,000.00	$ 2,500.00
Lab Supplies	$ 1,000.00	$ 1,000.00
Power Line Improvements	$ 7,200.00	$ 7,200.00
Advertisement/Conferences	$ 5,000.00	$ ---
Telephone	$ 1,200.00	$ 1,200.00
ALLOCATIONS		
Facility Upgrades	$ 30,000.00	$ ---
TOTAL COSTS	$159,780.00	$ 56,500.00

Table 4 -- Operating Expenses

The column on the right side represents the funds which are needed to meet the minimum expenses which will be incurred on an annual basis, i.e. to keep the "doors open". There is no money set aside to attract new business, and personnel are merely funded to answer questions and keep the equipment operational. This clearly does not support the long term health of the MSRF and would result in closure if funding levels did not rise in future years. However, it does establish a lower bound on the amount of sales the MSRF must have just to meet its expenses.

The column on the left is a more realistic long term budget for the MSRF. It includes part-time funding for a Director, secretary, technicians and student workers. The utilities are covered at a nominal level and some money is set aside for repair and calibration of instrumentation, laboratory supplies and office supplies. Enough money is set aside to partially fund attendance at three to five conferences per year and allow some travel to local industries to solicit new business. The power line improvement cost is applied for only the first three years to cover the cost of installing the main transformer feeding the laboratory and the additional power lines. In accordance with State and University policy, 10% of the cost of capital equipment must be set aside each year to fund upgrades and improvements in the facility. However, with the DOE Research Grant received, this allocation is being delayed for the first two years to provide a temporary discount to the MSRF's sponsors as a way of encouraging early use of the facility. This is intended to provide a boost in sales thereby allowing the MSRF to become financially self-sufficient much sooner than without the discount. Normally, users would like to delay their testing to see how the facility is operating before committing their funds. By encouraging early use of the MSRF by the sponsors, we hope to produce positive results with a favorably inclined clientele, thereby generating good "word of mouth" recommendations from actual customers, the best advertisement possible.

Table 5 demonstrates how the workload affects the hourly rate that must be charged to users of the facility. Therefore to keep the rates reasonably low, there must be high utilization. With multiple test beds installed and operational this utilization rate can approach or even exceed 100%, allowing even greater savings for the users.

Capacity	Hourly Rate *
25% (500 hrs/yr)	$320
50% (1000 hrs/yr)	$160
75% (1500 hrs/yr)	$107
100% (2000 hrs/yr)	$ 80

- Based on $160,000 annual operating budget. (Does not include labor to perform the tests.)

Table 5 -- Hourly Rates to Operate the Center

3. Revenues

Table 6 lists the pricing structure which has been established.

Service Offered	Sponsor's Rate	Non-Sponsor's Rate
Standard Tests on Motors & Generators		
Up to 15 hp	$ 500.00	$ 600.00
15 to 60 hp	$ 800.00	$ 1,000.00
60 to 300 hp	$ 1,400.00	$ 1,800.00
Specialized Testing		
15 hp Test bed	$ 50.00/hr	$ 60.00/hr
60 hp Test bed	$ 65.00/hr	$ 80.00/hr
300 hp Test bed	$ 100.00/hr	$ 125.00/hr
Student Workers	$ At cost + OPE	$ At cost + OPE
Technicians	$ 26.00/hr	$ 26.00/hr
Director	$ 60.00/hr	$ 60.00/hr
Supplies	At cost + 10%	At cost + 10%

Table 6 -- Pricing Structure

These rates will be adjusted annually to ensure costs are properly allocated to activities which generate the expenses. The rates for standardized testing have been set relatively low as a means of introducing first time users to the Center and to be competitive with other testing facilities. Since these are fixed prices the customers do not need to worry that there will be cost overruns. These rates can be justified because standardized tests require minimal administrative burden. There is little to negotiate in the contract, the final reports are generated by the data acquisition system and the testing procedures do not vary between tests.

To encourage early use of the test center and a corresponding revenue stream, a temporary discount will be offered to all EPRI members and their customers, and other test center sponsors. These discounts are shown in Table 6 above. This discount is being offered to allow sponsors to benefit from their investment in the center, for without them this project would not have been possible. In addition, a DOE research grant (exceeding $240,000) was given to the Energy Systems Group to allow the purchase of a broader range and more sophisticated instrumentation than was originally budgeted for this project. This has effectively allowed the center to perform its first upgrade before it began operating. Also, the next phase of this project (adding the 50 and 500 hp test beds) is already being discussed with the sponsors and funding will be provided for this upgrade. Therefore, the center will not allocate 10% of its capital cost for upgrades during the first two years as it normally would and this savings will be passed along to the sponsors in the form of lower rates for using the facility. Following this initial two year period, all customers will be charged the same rates and funds will be set aside to allow the center to retain its position as a state of the art facility.

4. Project Milestones

Award Construction Contract for Center	February 1995
Construction Begins	July 1995
Facility Operational	January 1996
All Systems Installed and Tested	March 1996
Open House	(TBD) 1996

Table 7 -- Project Milestones

If the financial goals established in this business plan are not met, the marketing plan will be reexamined and modified as needed. If necessary, the services offered by the facility will be changed to more closely match the needs of its customers. Also, the operating budget will be adjusted to meet the actual revenues.

Appendix A

Test Center Documents

MOTOR SYSTEMS RESOURCE FACILITY

(An EPRI/BPA Center at Oregon State University)

INVOICE

Phone: (541) 737-1867
Fax: (541) 737-0771

220 Electrical & Computer Engineering
Oregon State University
Corvallis, Oregon 97331-3211

No. __________
Date: __________

NAME

ADDRESS

CITY STATE ZIP

Customer Purchase Order No.		Quantity	Price
Standardized Testing Services:			
Induction Motors and Generators (IEEE Std 112)			
Up to 15 hp	$ 600.00	______	______
15 to 60 hp	$1,000.00	______	______
60 to 300 hp	$1,800.00	______	______
Synchronous Machines (IEEE Std 115)			
Up to 15 hp	$ 600.00	______	______
15 to 60 hp	$1,000.00	______	______
60 to 300 hp	$1,800.00	______	______
DC Machines (IEEE Std 113)			
Up to 15 hp	$ 600.00	______	______
15 to 60 hp	$1,000.00	______	______
60 to 300 hp	$1,800.00	______	______
Specialized Testing Services:			
Research Assistants	At cost + OPE	______	______
Technicians	$ 26.00/hr	______	______
Director	$ 60.00/hr	______	______
Supplies	At cost + 10%	______	______
Freight			______
	Total Due		______

Please Remit to: Attn: Bookkeeper
220 Electrical & Computer Engineering
Oregon State University
Corvallis, OR 97331-3211

For billing questions call:
(541) 737-2886
Please note invoice number
on payment.

SERVICE AND TESTING AGREEMENT

No. ________

between

State of Oregon acting by and through the
State Board of Higher Education on behalf of the
EPRI Center at OSU For Motor and Drive Research (ECOMDR)

and

(CUSTOMER)

Name: ________________________________
Address: ________________________________
____

WHEREAS, CUSTOMER desires the testing services of the ECOMDR in accordance with the work order attached to this Agreement.

WHEREAS, the performance of such testing is consistent, compatible and beneficial to the academic role and mission of Oregon State University as an institution of higher education and, in consideration of the mutual promises and covenants contained herein, the parties hereto agree as follows:

In exchange for the promises and other valuable consideration set forth below, the parties agree as follows:

1. **Purpose:** The purpose of the Agreement is to establish the responsibilities of the parties in providing a testing regimen for ____.

2. **Term:** This Agreement shall be effective on the date of last signature below, and shall remain in effect through ____________________ unless earlier terminated in conformance with this Agreement.

3. **Service Provided:** The ECOMDR shall perform the services described in the attached Work Order, which is made part of this Agreement by reference, and otherwise fully comply with the provisions in the attached Work Order.

4. **Payment for Services:** The ECOMDR shall invoice CUSTOMER for services provided under this Agreement, as specified in the attached Work Order.

5. **Insurance:** The ECOMDR agrees to maintain insurance levels, or self-insurance for the duration of this Agreement to levels necessary to protect against public body liability as specified in ORS 30.260-30.300.

6. **Indemnification:** CUSTOMER shall hold harmless the ECOMDR and OSU, their officers and employees from any claims or damages to property or injury to persons or for any penalties or fines, which may be occasioned in whole or in part by CUSTOMER's performance of this Agreement.

   Subject to the limitations and conditions of the Oregon Tort Claims Act, ORS 30.260-30.300, and the Oregon Constitution, Article XI, Section 7, the ECOMDR and OSU shall hold harmless CUSTOMER, its officers and employees from any claims or damages to property or injury to persons or for any penalties or fines, which may be occasioned in whole or in part by the ECOMDR's or OSU's performance of this Agreement.

7. **Termination:** This Agreement may be terminated by either party without cause upon giving thirty (30) days written notice of intent to terminate.

This Agreement may be terminated with less than thirty (30) days notice if a party is in default of the terms of this Agreement. Any such termination of this Agreement shall be without prejudice to any obligations or liabilities of either party already accrued prior to such termination.

8. **Confidentiality:** To the extent permitted by the Oregon Public Records Law, OSU agrees to keep confidential any CUSTOMER proprietary information supplied to it and clearly marked by CUSTOMER during the course of testing performed by the ECOMDR, and such information will not be included in any published material without prior approval by CUSTOMER, such approval is not to be unreasonably withheld.

9. **Applicable Laws:** Both parties shall comply with all applicable federal, state, county and local laws, ordinances and regulations applicable to this Agreement.

10. **Assignment:** This Agreement is binding on each party, its successors, assigns, and legal representatives and may not, under any condition, be assigned or transferred by either party without prior written approval by the other party.

11. **Use of Data**: The ECOMDR agrees to follow all applicable procedures and Standards specified in the Work Order, but makes no warranty with regard to such data or test results. CUSTOMER agrees to assume sole responsibility for the use of any data or test results produced by this agreement.

12. **Publication**: CUSTOMER will not include the name of the ECOMDR or OSU in any advertising, sales, promotion, or other publicity matter without prior written approval of the ECOMDR. The ECOMDR shall be permitted to publish data resulting from this agreement when it appears as a compilation with data from other tests. The ECOMDR will obtain written approval from CUSTOMER prior to publishing CUSTOMER'S name or data resulting from this agreement.

13. **Changes and Amendments:** This Agreement constitutes the entire Agreement between the parties. There are no understandings, agreements or representations, oral or written, not specified herein regarding this Agreement. No waiver, consent, modification or change or terms of this Agreement shall bind either party unless in writing and signed by all parties. Any such waiver, consent, modification or change shall be effective only in the specific instance and for the specific purpose given. CUSTOMER, by signature below of its authorized representative, acknowledges having read and understood the Agreement and CUSTOMER agrees to be bound by its terms and conditions.

IN WITNESS WHEREOF, the parties hereof have caused this Agreement to be executed as of the date set forth herein by their duly authorized representatives.

STATE OF OREGON ACTING BY AND THROUGH THE STATE BOARD OF HIGHER EDUCATION ON BEHALF OF THE EPRI CENTER AT OSU FOR MOTOR AND DRIVE RESEARCH

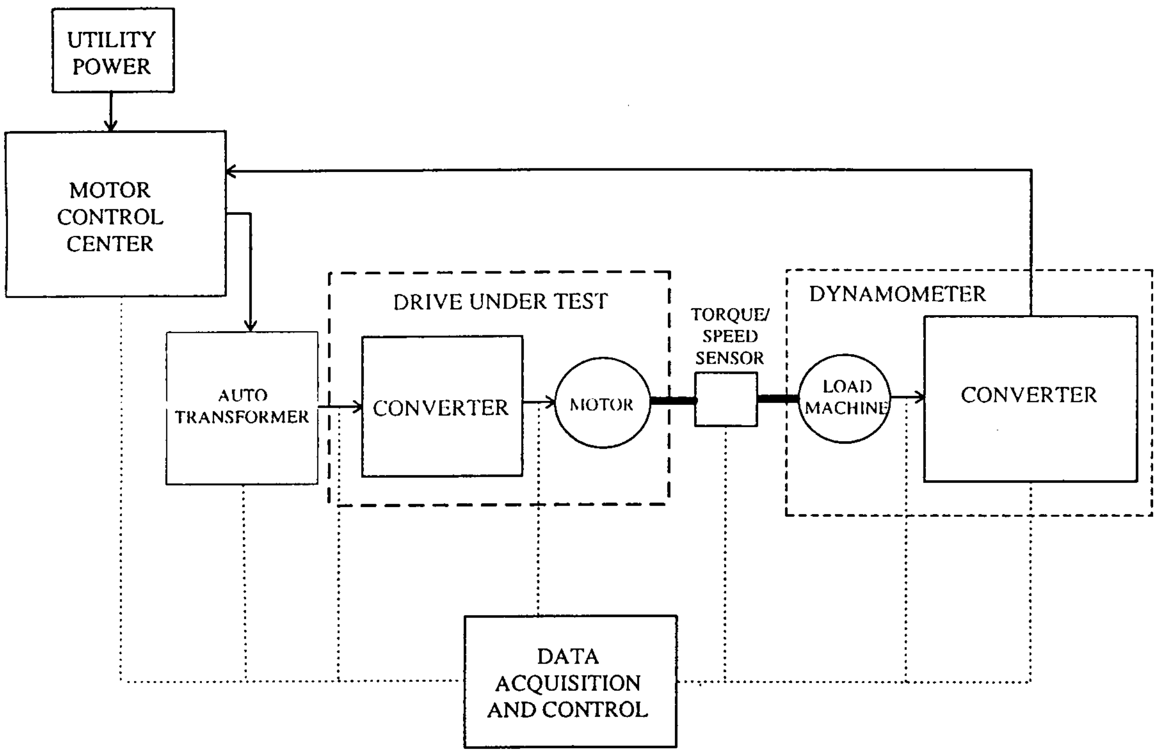
CUSTOMER

Alan Wallace **Date**
Director, ECOMDR

Name **Date**

Robert L. Halvorsen **Date**
Contract Administrator

THE MOTOR SYSTEMS RESOURCE FACILITY



THE MOTOR SYSTEMS RESOURCE FACILITY (MSRF)

Electrical & Computer Engineering
Oregon State University
Corvallis, Oregon 97331-3211
Phone (541) 737-1867
Fax (541) 737-0771
http://www.ece.orst.edu/~msrf

OBJECTIVES AND FUNCTION

The Motor Systems Resource Facility (MSRF) was initiated in late 1993 by a consortium of sponsors to meet an identified, growing need for the industrial customer of power utilities. The focus of the facility is its testing laboratory in which electrical machines, adjustable speed drives and variable speed generators, and their related converters and controls can be evaluated. In addition to testing to recognized industrial standards, the facility is intended as a source of advice, information, reference and instruction in issues and equipment related to electrical machines and their operation.

OSU was chosen as the location based on its history of successful projects in this area and the expertise and experience developed over ten years of services to regional utilities and industries. The facility is operated by OSU College of Engineering research faculty, electrical and mechanical technical staff, and post graduate students. This provides and independent resource to industry combined with a research and education function for the University.

SPONSORS

Electric Power Research Institute
Bonneville Power Administration
US Department of Energy
Pacific Gas & Electric

CAPABILITIES

Motors, Generators and Controllers up to 300 h.p. (500 h.p. in 1996)

750 KVA Power Supply
- Variable voltage input (0-600 VAC)
- Three phase adjustment while loaded (balanced or unbalanced)

Four Quadrant Dynamometer Converter
- Programmable Torque & Speed Modes
- Vector Control for full load testing over the full speed range
- (0-4000 rpm, bi-directional)

Mechanical Measurements
- Torque
- Speed
- Power

Power Quality
- Steady-state and transient measurements
- Harmonic analysis
- THD
- K Factor

Remote Data Acquisition & Recording
- Instantaneous & RMS values using a Virtual Instrumentation System

Local Data Acquisition for transient detection & analysis

Routine Testing
- Full Load, No Load
- Transient Response
- Locked Rotor
- Harmonic & Vibration Measurement

STAFF

Director
Alan Wallace; Professor, Electrical & Computer Engineering; electrical machine design and performance, adjustable speed drives and variable speed generation, testing techniques.

Associates
Rene Spee; Associate Professor, Electrical & Computer Engineering; adjustable speed drives, power electronic converters, power system issues.

Corwin Alexander; Emeritus Professor, Electrical & Computer Engineering; machine analysis and parameters, power systems, data acquisition.

Annette von Jouanne; Assistant Professor, Electrical & computer Engineering; adjustable speed drives, power electronics, utility interface issues & power quality.

Greg Wheeler; Associate Professor, Energy Extension; energy audits, industrial site testing, power quality.

OSU Electrical & Mechanical faculty in all related disciplines as required.

Technical
Charles Meitle & Manfred Dittrich; mechanical support.

Arthur Neeley; electrical support.

Steve Wilcox; computer and instrumentation support.

Appendix B

Other Test Facilities

Industrial
Electrotechnology
Laboratory

IEL MOTOR TEST CAPABILITIES *January 1994*

The Industrial Electrotechnology Laboratory can measure the efficiency of new and repaired motors at full and partial loads.

The Lab is equipped to perform dynamometer load tests on 3 phase AC induction motors per IEEE 112B, NEMA MG-1 and CSA C-390 test standards. Locked rotor and breakdown torque testing is also available. Test repeatabilitity is in the range of 0.2%.

The ranges of motor sizes that can be tested are limited by the following torque measurement and power supply constraints.

Horsepower limits for Voltage/Speed Configuration (Customer)

Speed	230V	460V	575V
900	75	75	75
1200	75	100	100
1800	75	150	150
3600	75	150	150

Foot Mount, "C" flange and "D" flange motor mounts can be tested. Call the IEL Operations Manager, Dominic Dirisio, at (919) 515-3941 to schedule motor tests.

Shipping address: Industrial Electrotechnology Laboratory
Centennial Campus - NCSU
2401 Research Drive, Room 1217
Raleigh, NC 27695

TESTING SERVICES

— Energy efficiency evaluation;
— Motor and adjustable speed drive (ASD) efficiency tests;
— Harmonic analysis of motor and drive systems.

MAIN ELEMENTS OF THE TESTING FACILITY

— Power supply: three phase variac 720 V, 500 kVA;
— Hewlett Packard 3852 data acquisition system with Hewlett Packard 382 computer;
— Hymmelstein & Co. speed and torque transducers;
— Scientific-Columbus power, current, voltage and var transducers.

STANDARDS: CSA C-390
NEMA MG-1
IEEE 112

TECHNICAL CHARACTERISTICS OF THE THREE TEST BENCHES

1 to 15 HP:

Brake type	DC generator
Manufacturer	General Electric
Model	SCD132TA
Power	13 kW

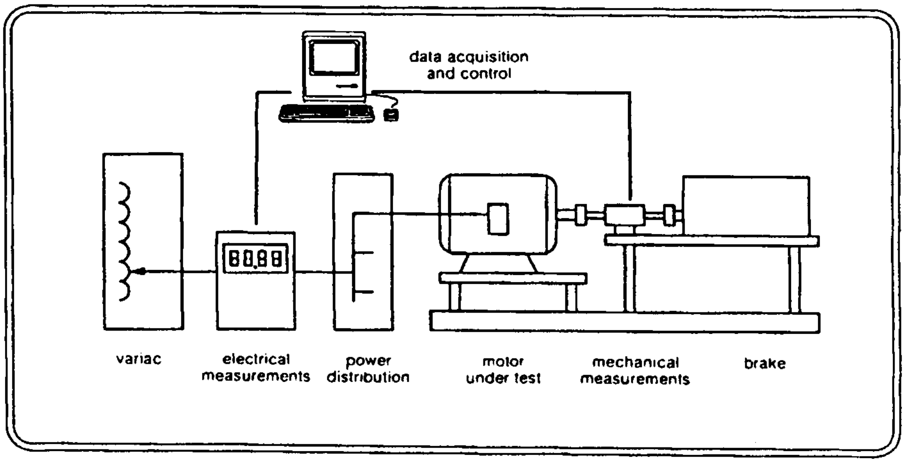
15 to 150 HP:

Brake type	Water brake
Manufacturer	Clayton
Model	CAM 250
Power	250 HP (185 kW)

150 to 500 HP:

Brake type	Eddy current brake
Manufacturer	Midwest
Model	2025-DG
Power	700 HP (520 kW)

SIMPLIFIED DIAGRAM



LTEE

Appendix B

MSRF STARTUP PROCEDURE

Note: Only those individuals specified in writing by the Director of the MSRF are qualified to operate the equipment in this laboratory.

DEDICATED SUPPLY PANEL

Precautions

- Before closing the supply breaker, ensure that all cabinets on MCC-1 are closed and all breakers on MCC-1 are open and pinned to prevent inadvertent operation.

Initial Conditions

1. All breakers on MCC-1 and MCC-2 are open and pinned or locked.

2. The utility supply transformer is energized as noted by the 60 Hz hum.

3. The supply breaker is "OPEN" and "DISCHARGED" as noted by the flags on the breaker.

4. Both emergency shutdown switches are pulled out and the covers are in place.

5. The disconnect near the isolation transformers that powers the emergency shutdown switches is shut.

Steps

1. Extend the breaker charging handle. Pump the handle up until it pumps freely. (About 10-15 steps) One flag should now read "CHARGED" and the other "OPEN".

2. Stand to the left side of the cabinet facing the power meter, reach across to the breaker and press the black button marked "PUSH TO CLOSE" to shut the breaker. Verify that the flags now read "DISCHARGED" and "CLOSED".

3. If the breaker failed to shut, verify the above initial conditions and repeat the above steps once. If the breaker fails to remain shut on the second attempt, notify the Director of the test center.

<u>MCC-1</u>

Precautions

- Before closing any of the breakers on MCC-1, ensure that all cabinets are closed and no wires or cables powered by the system are left exposed.

- Ensure that the shafts of the dynamometer and machine under test are free to spin and all mechanical connections are securely fastened, including the shaft couplings, torque/speed transducer, motor mounts, motor table adjustment mechanisms, and motor power connections. If any connections are suspect, contact the mechanical technician or the Director.

- Ensure that the mezzanine door, rollup door and double doors are shut and locked to prevent accidental entry by unauthorized personnel.

Initial Conditions

1. The main contactor on the Kenetech converter is open and the cabinet is shut.

2. All three mode control switches on the autotransformers are in manual.

3. Control power from the junction box in the control room is applied.

4. The disconnect for the dynamometer blower motor is shut and the motor starter is off.

Steps

1. Ensure that all breakers on MCC-2 are locked open.

2. Spin the shafts for the dynamometer and machine under test to verify that they are free and there is not excessive binding or loose parts.

3. Read the incoming line and phase voltages on MCC-1 and verify that they are at the correct values. (Line voltage 460-500, Phase voltage 265-289)

4. Unpin and shut the breakers in the following order.
   A. Either 300 or 50 HP Dynamometer Controller, as required.
   B. MS-500 Control (Verify that the green lights on the motor starter cabinet and test bed are lit.)
   C. Busway to VXFMR. (Listen for the cooling fans on the autotransformers to start.)

AUTOTRANSFORMERS

Note: For a "Line Start" the voltage will be set at rated voltage when the motor starter contacts are closed. For a "Soft Start" the voltage may be set at a predetermined, but lower, value to reduce the in-rush current.

Steps

1. Verify that a 0 V. signal is being sent from the control room to the autotransformers.

2. Switch each of the three mode control switches to auto.

3. On MCC-2, unlock and shut the appropriate control breaker for the voltage range to be used for testing (i.e. 240 or 480V).

4. From the control room, raise the autotransformer voltage to the desired value checking for balance between the phases. Read the output voltage on the panel meters, on MCC-2 and from the control room.

MCC-2

Steps

1. Determine which circuit breaker is best suited to provide protection for the system being tested based on frame size, sensor rating, adjustment of trip setpoints and existence of ground fault protection. A secondary consideration can include instrumentation range.

2. If use of the trip indicator module is expected, install it on the desired breaker at this time.

3. Verify that the "on" light to the desired breaker is functional by using the push-to-test feature.

4. Verify that all other breakers feeding the motor starter are open and locked. Verify that the red lights on all other breakers are off and the green lights on motor starter and test bed are lit.

5. Unlock and shut the selected breaker.

DRIVE

1. Ensure that the Emergency Shutdown switch is pulled out.

2. Close the main contactor.

3. Start the dynamometer motor cooling fan by closing the disconnect and switch located on the side of the drive.

CONTROL COMPUTER

1. Ensure that the fiber optic interface has electrical power and is connected to both the control computer and the drive.

2. Turn on the computer and monitor.

3. At the DOS prompt type "asd_300" and enter. The control screen should now appear.

4. Press F10 and set the operator adjustable parameters to the desired values for the test being performed. Be careful not to set the allowable values beyond the safety limits of the devices being tested, or too restrictive as to cause spurious shutdown of the dynamometer.

5. Press F1 to select the desired mode (i.e. Test Torque, Speed, Line_Only). Set the desired value for torque or speed, paying particular attention to the magnitude and direction.

6. Verify that the drive is functioning correctly by monitoring the sequence of operation in the status block and by comparing available measurements with those displayed by the control computer. Also verify that the cooling fans above the Drive start.

7. If a fault occurs, press "CTRL c" to clear the alarm. Refer to the operator's manual for a list of faults and their causes.

8. If the drive must be shutdown, press "s" for stop. If removing the load will cause an instability in the system under test, shut it down also.

9. If the motor shaft must be stopped quickly, place the dynamometer in speed mode and enter "0" for the commanded speed.

MSRF SHUTDOWN PROCEDURE

DAILY SHUTDOWN

Precautions

- The dynamometer and/or unit under test may be damaged if the system is not shutdown in the proper sequence.

Steps

CONTROL COMPUTER

1. Unload the system being tested by adjusting that system or the dynamometer as appropriate.

2. Open the motor starter relay contacts by pressing the stop button.

3. Press "s" for stop on the control computer.

4. Enter "o" or click on the "OK" box on the control computer. The dynamometer should now be completely unloaded.

MCC-2

1. Open the circuit breaker which has been supplying the load. Verify that the red light on the breaker turns off.

DRIVE

1. Open the main contactor on the Drive cabinet.

2. Turn off the cooling fan for the dynamometer.

AUTOTRANSFORMERS

1. Reduce the output voltage to zero.

2. Open the breaker supplying the autotransformers and verify that the cooling fans turn off.

MCC-1

1. Open the breaker supplying the converter.

2. Open the MS-500 breaker.

EXTENDED SHUTDOWN

Steps

1. First complete the Daily Shutdown Procedure described above.

2. Turn off the breaker in the junction box in the control room to turn off the lights on the motor starter cabinets.

3. If desired, open the dedicated supply breaker by pushing one of the emergency shutdown switches. Verify that the breaker opens by monitoring the voltage on MCC-1.

EMERGENCY SHUTDOWN

1. If electrical power must be quickly removed from the system being tested or the dynamometer, simply press one of the emergency shutdown switches located near the exit to the control room and the double doors in the laboratory. This will deenergize all of the circuits above 120 volts in the event of a fire or severe accident and allow the shaft to gradually stop.

2. If the shaft must be stopped quickly due to excessive vibration or debris being thrown free, open the motor starter contacts by pressing the "stop button" on the cabinet or in the control room and set the dynamometer speed to zero.